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AN AUTOMATED PROCEDURE FOR SLOPE MAP CONSTRUCTION. VOLUME I. DE--ETC(U)
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UNCLASSIFIED WES-TR-M-77-3-VOL-1 NL

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TECHNICAL REPORT M-77-3

AN AUTOMATED PROCEDURE FOR SLOPE MAP CONSTRUCTION

Volume I

DESCRIPTION AND INSTRUCTIONS FOR USE OF THE AUTOMATED PROCEDURE

by

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October 1977

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Project 4A152121A896, Task 01, Work Unit 006
Project 1E865803M730

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(14) WES-TR-M-77-3-VOL-1

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report M-77-3-VOL-1

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

(6)

4. TITLE (and Subtitle)
AN AUTOMATED PROCEDURE FOR SLOPE MAP CONSTRUCTION. VOLUME I. DESCRIPTION AND INSTRUCTIONS FOR USE OF THE AUTOMATED PROCEDURE.

(9)

5. TYPE OF REPORT & PERIOD COVERED
Final report. 1 Jun 75-30 Jun 76,

6. PERFORMING ORG. REPORT NUMBER

(10)

7. AUTHOR(s)
Horton/Struve

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Mobility and Environmental Systems Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Project 4A152121A896, Task 01, Work Unit 006, and Project 1E865803M730

11. CONTROLLING OFFICE NAME AND ADDRESS
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

12. REPORT DATE
(11) Oct[redacted]77

13. NUMBER OF PAGES
146 (12) 104p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Volume I--Approved for public release; distribution unlimited.
~~Volume II--Distribution limited to U. S. Government agencies only; test and evaluation; June 1977. Other requests for this document must be referred to U. S. Army Engineer Waterways Experiment Station (WESFE).~~

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
~~(17) I1~~ (16) 1E8658Ø3M73Ø

18. SUPPLEMENTARY NOTES
Volume I--DESCRIPTION AND INSTRUCTIONS FOR USE OF THE AUTOMATED PROCEDURE
Volume II--LISTING AND GLOSSARY FOR PROGRAM SLOPEMAP

AD-B023652L

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Computer programs
Mapping
SLOPEMAP (Computer program)
Slopes
Topographic maps

Ø38 1ØØ

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An automated procedure for constructing slope maps was developed and demonstrated in this study. The procedure consists of three sequential parts: (1) input of surface elevation values by means of a matrix of elevation values referred to as an elevation grid array, (2) calculation of slope magnitudes and directions by the computer program SLOPEMAP, and (3) construction of slope maps using various SLOPEMAP output products.

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Unclassified

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20. ABSTRACT (Continued).

The form of input elevation data selected for use by SLOPEMAP to be prepared in advance of program execution is an orthogonal two-dimensional matrix, each element of which is the elevation of the topographic surface at that matrix (or grid) point. At run time, SLOPEMAP inputs these elevation values and calculates the slope magnitude and direction of each input grid point by employing approximation methods that use the elevation values of the grid point in question and its nearest and next nearest neighbors. Then, depending on the selected user options, the calculations are recorded or displayed in one or more of the following forms: (1) printer swath dumps, (2) magnetic tapes, (3) punched cards, and/or (4) drum or cathode ray tube (CRT) graphic plots that delineate slope classes selected by the user.

Volume I of this two-volume report contains detailed instructions describing the execution of SLOPEMAP and two examples demonstrating the slope map construction procedure. Volume II provides a computer listing of the program SLOPEMAP and a glossary of program variables. SLOPEMAP was coded with Fortran IV to ensure future implementation ease on other computer systems.

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PREFACE

The study reported herein was conducted under two projects: (a) Department of the Army (DA) Project 4A152121A896, "Environmental Quality for Construction and Operation of Military Facilities," Task 01, "Environmental Quality Management for Military Facilities," Work Unit 006, "Methodology for Characterization of Military Installations Environmental Baseline," sponsored by the Directorate of Military Construction, Office, Chief of Engineers (OCE); and (b) DA Project 1E865803M730, "Research and Development Computer and Information Science Support," sponsored by the Engineer Information and Data Systems Office, OCE, under the "Improved Data Effectiveness and Availability" program. Mr. Vincent Gottschalk was the OCE Technical Monitor.

The study was conducted during the period 1 June 1975 to 30 June 1976 by personnel of the Environmental Simulation Branch (ESB), Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES). The work was under the direct supervision of Dr. V. E. LaGarde, ESD, and Mr. J. K. Stoll, Chief, ESB, and under the general supervision of Messrs. B. O. Benn, Chief, ESD, and W. G. Shockley, Chief, MESL. Drs. H. Struve, ESB, and LaGarde were responsible for the slope map methodology and associated computer programs, and Dr. Struve prepared the report.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors of the WES during the study and report preparation. Mr. F. R. Brown was Technical Director.

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VOLUME II

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
U. S. Customary to Metric (SI)		
inches	2.54	centimetres
feet	0.3048	metres
degrees (angular)	0.01745329	radians
Metric (SI) to U. S. Customary		
centimetres	0.3937007	inches
decimetres	0.3280839	feet
metres	3.280839	feet
kilometres	0.6213711	miles (U. S. statute)
square kilometres	0.3861021	square miles (U. S. statute)

AN AUTOMATED PROCEDURE FOR SLOPE MAP CONSTRUCTION

VOLUME I: DESCRIPTION AND INSTRUCTIONS FOR USE OF THE AUTOMATED PROCEDURE

PART I: INTRODUCTION

Background

1. It is the policy of the Department of the Army to implement rigorously the National Environmental Policy Act of 1969 and its derivative statutes as outlined by Executive Order and other Federal and state environmental statutes. This policy requires that the Army must make a deliberate and conscientious effort to carry out its mission so as to:

a. Preserve unique and important ecological, aesthetic, and cultural components of our national heritage.

b. Conserve and use wisely the natural resources of our nation for the benefit of present and future generations.

c. Restore, maintain, and enhance the natural and man-made environment in terms of its productivity, variety, spaciousness, beauty, and other measures of quality.

d. Create new opportunities for the American people to use and enjoy their environment.

2. Reflections on the many and diverse activities carried out by the Army that could adversely impact on items a through d above make it obvious that Army planners (at all levels) need readily accessible data on a large variety of environmental elements including topography, soils, geology, vegetation, climatology, surface water, groundwater, land use, and others. Further, for the most part, these baseline data must be in a form compatible with modern computer facilities because of the vastly expanded requirement for data analysis and display. The managers of the Army's research project "Environmental Quality for Construction and Operation of Military Facilities" have adopted a concept for environmental data analyses that includes the extensive use of computerized mathematical prediction models; therefore, a prime criterion for the selection of an element to be incorporated in a baseline

data base is its requirement for the prediction of environmental effects caused by an Army activity.

3. This report describes a new computerized procedure for mapping slope, a topographic baseline element. Data on terrain slope is needed for a wide variety of uses including procedures for evaluating the impact on the environment of military activities, such as construction, field maneuvers, and maintenance (preparation of environmental impact assessments (EIA's) and statements (EIS's)). Commonly, plans for the mitigation of adverse effects must take into account the effect of terrain slope on such things as soil erosion (see Reference 1), surface runoff, land revegetation, wildlife habitat enhancement and preservation, equipment operation for land restoration, and facilities siting. Further, data on terrain slopes are frequently needed in general terrain intelligence products, in correcting satellite and aircraft scanner data, and in designing and evaluating most ground weapons systems and all military ground-contact vehicles.

4. The manual techniques currently used for mapping slopes from topographic maps are slow and yield somewhat inconsistent results. Even under optimum circumstances, there exists a probability of error in manually constructed slope maps simply because of the many subjective decisions required in the procedure. The resulting cost of constructing slope maps manually, as well as the inherent risk of error in the final product, indicates clearly the need to develop faster and more reliable techniques for producing slope maps.

5. The Defense Mapping Agency Topographic Center (DMATC) has developed a system of computer programs[2] that uses a grid network of ground-surface elevations and converts these elevations into a corresponding network of slope values. The DMATC procedure is based on the least squares fit of a plane in the direction of maximum inclination and does not yield slope data of an accuracy that is required in many problems dealing with the impact of military activities on the environment. The least-squares-fit method (designated plane algorithm in this report) was evaluated and compared to two other calculation methods. The results of this comparative evaluation are presented in Part II.

6. The initial steps in developing an improved method of automating slope calculations and slope map construction had already been completed by personnel at the U. S. Army Engineer Waterways Experiment Station (WES) prior to the initiation of this project. These steps include the procedures necessary for representing a topographic surface in a form that is compatible with digital computers. The form currently used at the WES is an orthogonal two-dimensional matrix, each element of which is the elevation of the topographic surface at that matrix (or grid) point. The two dimensions of the matrix are designated X and Y , and the elevation of the surface is designated Z . Since the X and Y values are understood from the position in the matrix, only the Z values are actually recorded. The matrix, frequently referred to as an elevation grid array, can be produced from source data obtained from field survey data, aerial photography, or topographic maps.

7. A convenient source of elevation data frequently used at the WES is a topographic map of the area of interest. The semiautomated procedure for generating an elevation grid array using topographic maps requires that one manually move a cursor along each contour line of the topographic map and record X , Y , and Z coordinates. This process, called digitizing, produces a computer magnetic tape of stored X , Y , and Z values. The tape can then be submitted as input data to a WES computer program[3] to generate the final elevation grid array. Automated techniques for digitizing the contour lines by optical scanning processes are now being developed at the WES and should, when completed, significantly reduce the time and cost of producing elevation grid arrays.

Purpose

8. The purpose of the study was to develop and demonstrate the use of an automated procedure for constructing slope maps from a digital topographic data base, i.e. from a terrain surface defined by an elevation grid array (see paragraph 6), so that personnel at Army installations could produce cost-effective baseline slope data (i.e. slope maps) to support a variety of military activities requiring preparation of Environmental Impact Assessments and Statements (EIA's/EIS's).

Approach and Scope

9. The approach was to initially select several methods of calculating slope values from an elevation grid array. Next, it was necessary to develop a computer algorithm for each method and determine which algorithm would best describe slopes on most three-dimensional terrain surfaces. The selection of the best algorithm was based on comparing exact slope values and algorithm slope values computed from three synthetic elevation grid arrays derived from three different mathematically defined surfaces. The equations representing each surface were precisely defined and continuous. This meant that there were no sudden jumps in the equations, and all the points on the curves were differentiable. Therefore, at any point on the surfaces, the derivative (slope) could be found. The derivatives derived from these equations were the "exact slopes." Once constructed, the synthetic grid arrays were used as input arrays to each slope algorithm. The slopes computed with each algorithm were then compared with the exact slopes on a grid point by grid point basis, and the algorithm that produced slope values in agreement most frequently with the exact values was selected.

10. After the optimum algorithm had been selected, an automated procedure was developed to output the slope magnitudes in numerical and classed forms on a high-speed printer, magnetic tape, and computer punch cards. Subroutines also were developed to output specified slope class ranges graphically on drum or cathode ray tube (CRT) plots and to output slope vectors in component form on magnetic tape.

11. The operation and demonstration of the automated procedure is described in detail in Volume I of this two-volume report. Two widely different terrain surfaces were selected for demonstrating the procedure. The computer-constructed slope maps for the two sites were compared with manually constructed slope maps in terms of accuracy and cost. Volume II contains a FORTRAN IV listing of the computer program and a glossary of program variables.

PART II: DEVELOPING, TESTING, AND EVALUATING COMPUTER ALGORITHMS FOR CALCULATING SLOPE

12. To accomplish the objective of this study, it was first necessary to select several different methods for calculating terrain slopes; three methods were selected, and a computer algorithm was developed for each. The slopes calculated with the algorithms were then compared with exact slope values determined by differential calculus for three mathematically defined surfaces, and the algorithm that provided the optimum trade-off between accuracy and cost was selected for use in the automated procedure for slope map construction.

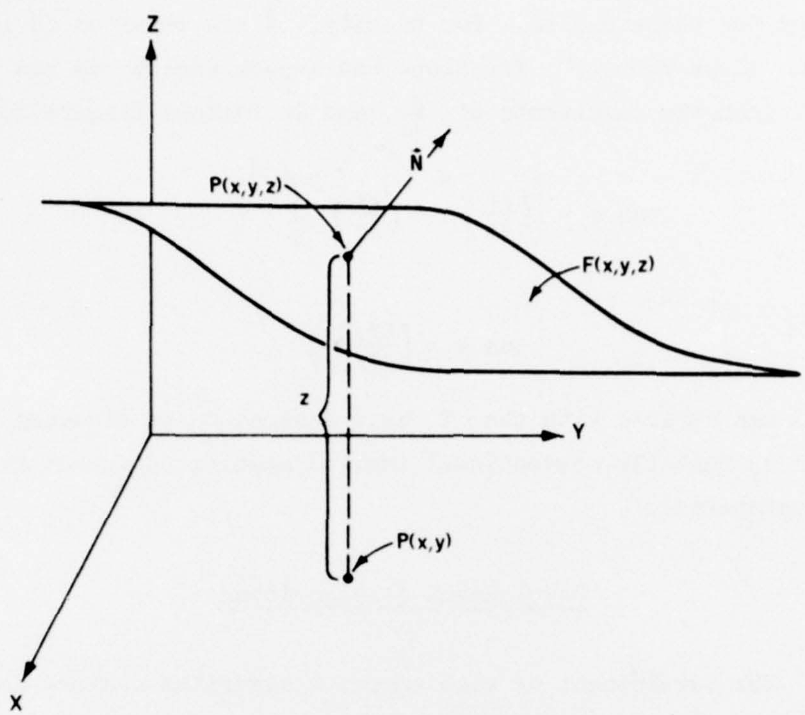
Theoretical Considerations

13. The theoretical considerations relevant to slope calculation are briefly discussed in this section to provide a common mathematical framework from which all the slope algorithms will be developed.

14. Points on a three-dimensional terrain surface can be described by an equation of the form $z = f(x,y)$, where z is defined as the perpendicular distance from the terrain surface to a point $P(x,y)$ lying in the X-Y reference plane of a Cartesian coordinate system. The perpendicular distance z (Figure 1) is then the elevation of the terrain surface at the point $P(x,y,z)$ with respect to the X-Y reference plane.

15. If the equation of the terrain surface is expressed in its more general form, i.e., $F(x,y,z) = c$, where the constant c is set equal to zero so that $F(x,y,z) \equiv z - f(x,y)$, it can be shown that the gradient of $F(x,y,z)$ is a vector, $\vec{N}$, normal to the surface $F(x,y,z)$ at the point $P(x,y,z)$. The vector $\vec{N}$ can then be expressed as

$$\vec{N} = \vec{\nabla} F = -\frac{\partial f}{\partial x}\hat{i} - \frac{\partial f}{\partial y}\hat{j} + \hat{k} \tag{1}$$



NOTE: THE PERDENDICULAR DISTANCE z (ORIGINATING AT THE POINT P (x, y) ON THE X-Y REFERENCE PLANE) REPRESENTS THE ELEVATION OF THE POINT P (x, y, z) ON THE SURFACE F (x, y, z). THE SURFACE NORMAL VECTOR Ñ IS SHOWN PERPENDICULAR TO THE SURFACE F (x, y, z) AT THE POINT P (x, y, z) (ORIENTATION ANGLES OF Ñ ARE SHOWN IN FIGURE 2)

Figure 1. Theoretical representation of a three-dimensional terrain surface

where

$\vec{\nabla}$ = the Cartesian vector differential operator del

$\hat{i},\hat{j},\hat{k}$ = the orthogonal unit vectors directed along the X, Y, and Z axes of the Cartesian coordinate system

Figure 2 shows an example of $\vec{N}$ normal to the surface, together with its orientation angles ϕ and θ , which are defined as the zenith and azimuth angles of $\vec{N}$, respectively. Since the terrain slope and aspect angles, defined by the magnitude and direction of tilt from the horizontal of a plane perpendicular to $\vec{N}$, are equivalent to the zenith and azimuth angles, respectively, no distinction is made in the

terminology for these angles. For brevity, $\vec{N}$ is referred to in this study as a "slope vector." The slope and aspect angles can now be calculated from the components of $\vec{N}$, and it follows (Figure 2) that

$$\tan \phi = \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2\right]^{1/2} \tag{2}$$

and

$$\tan \theta = \left(\frac{\partial f/\partial x}{\partial f/\partial y}\right) \tag{3}$$

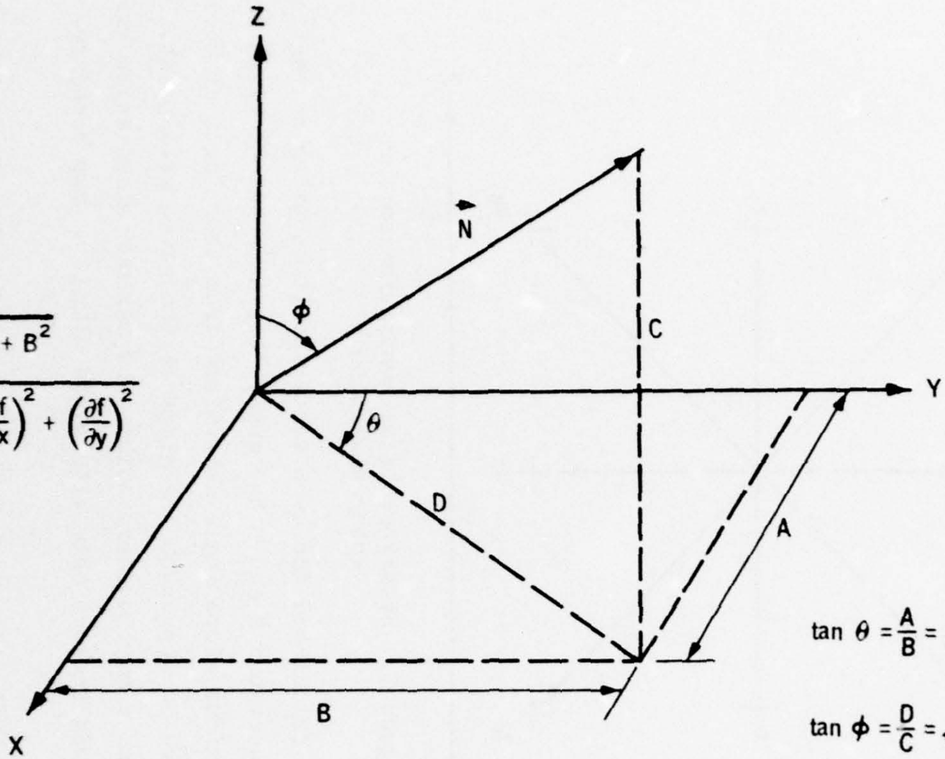
Equation 3 was derived with the Y axis assumed to be directed toward true north so that the conventional implied meaning of aspect angle would be maintained.

Development of Algorithms

16. The development of each computer algorithm centers about methods of calculating the expressions for the tangent of the slope and aspect angles in Equations 2 and 3. Before this can be achieved, however, an analytical expression must first be determined for $f(x,y)$ that approximates the terrain surface, and second, the partial derivatives of $f(x,y)$ with respect to x and y must be obtained. In this study, the approximations of $f(x,y)$ were restricted by the format of the elevation input data. The actual form of the input data will be discussed more completely in Part III, but the essentials to be understood at this point are that the data were formatted prior to execution of the automated procedure into an elevation grid array (see paragraph 6) with the same fixed grid spacing in both the x and y directions and with an elevation value assigned to each grid location. Thus, the development of the three slope algorithms discussed in the following paragraphs necessarily conforms to these requirements for input of the elevation data.

Vector algorithm

17. The vector algorithm was selected for development first because of its conceptual and programming simplicity. The algorithm



$A = \frac{-\partial f}{\partial x}$

$B = \frac{-\partial f}{\partial y}$

$C = 1$

$$D = \sqrt{A^2 + B^2} = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

$$\vec{N} = A\hat{i} + B\hat{j} + C\hat{k}$$

$$\tan\theta = \frac{A}{B} = \left(\frac{\partial f/\partial x}{\partial f/\partial y}\right)$$

$$\tan\phi = \frac{D}{C} = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

Figure 2. Orientation angles ϕ and θ of $\vec{N}$ (vector normal to the surface, $F(x,y,z) = z - f(x,y)$) and their trigonometric relations with the components of $\vec{N}$

established, as a local origin, the grid point whose slope and aspect angles were to be evaluated and performed a search around the grid point using the four nearest neighbors and the four next-nearest neighbors as vector termination points (Figure 3). The slope and aspect

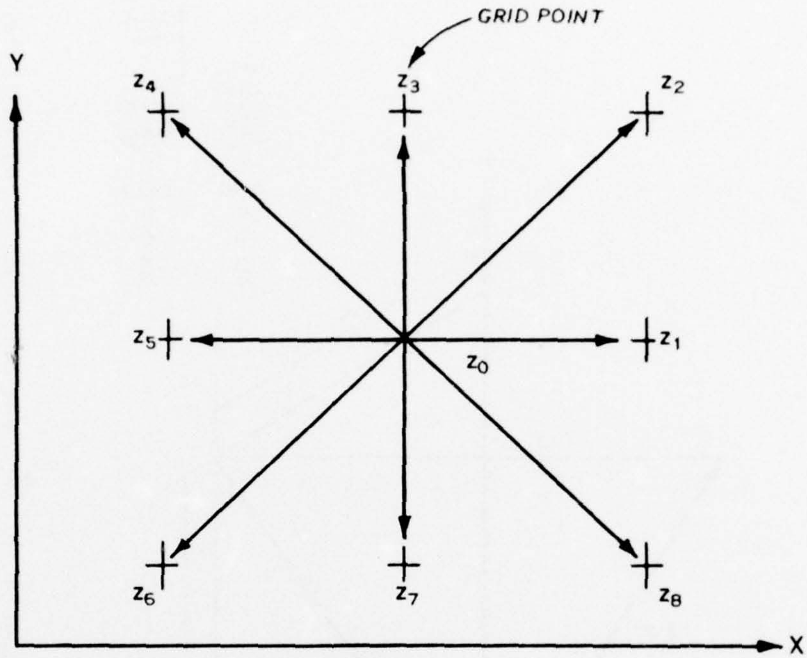


Figure 3. Reference plane configuration for vector algorithm

angles were then calculated for each vector position using as partial derivatives in Equations 2 and 3 the analytical expressions given in Table 1. The maximum slope angle determined from these sets of derivatives was selected to represent the slope of the given grid point. If the grid point was a map boundary point, the maximum slope angle was selected from among vectors only within and along the map boundary.

Plane algorithm

18. The scheme followed for the plane algorithm was to select the plane with the greatest slope value from among four surrounding planes. The planes were defined by the adjacent nearest-neighbor grid points (Figure 4) and the grid point being evaluated. The slope and aspect angles were calculated from the expressions for the partial derivatives

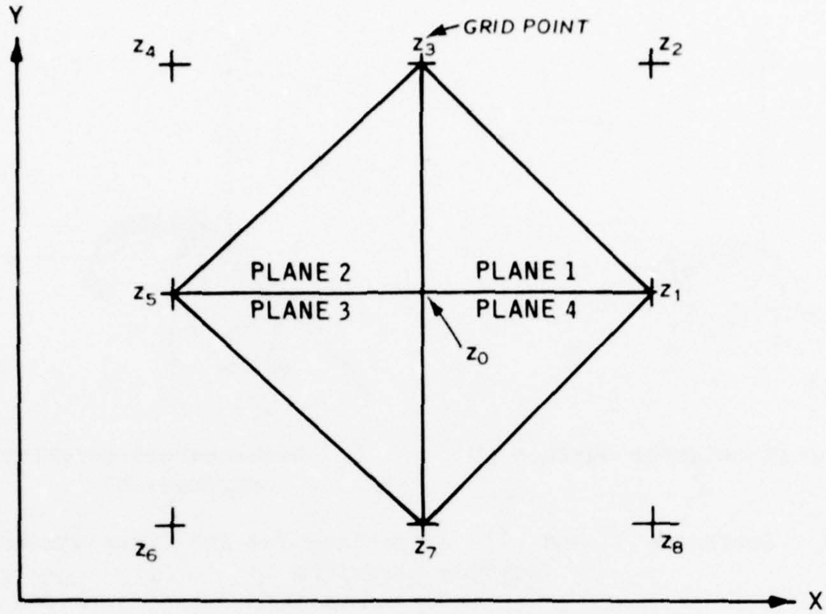


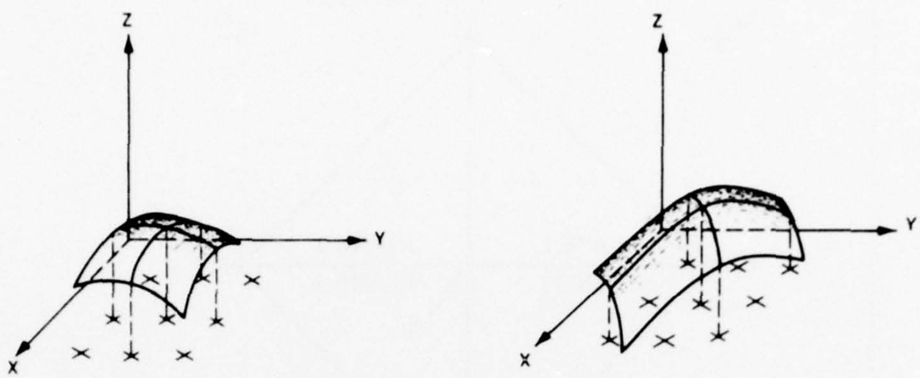
Figure 4. Reference plane configuration for plane algorithm

of $f(x,y)$ given in Table 1. Again, if the grid point to be evaluated was a map boundary point, the maximum slope was selected from among planes only within the map boundary.

Three-dimensional surface algorithm

19. The surface algorithm was used to calculate the maximum slope from two fitted three-dimensional surfaces S and S' . The nearest-neighbor grid points and the grid point to be evaluated determined the S surface (Figure 5a), and the next-nearest-neighbor grid points and the grid point to be evaluated determined the S' surface (Figure 5b). The slope value assigned to the central grid point was calculated from the maximum partial derivatives of $f(x,y)$ derived from both surfaces (Table 1). The maximum partial derivatives did not necessarily come from the same surface. Thus, two independent opportunities were available for determining maximum $\partial f/\partial x$ and maximum $\partial f/\partial y$ by the surface algorithm.

20. The fitting procedure for each surface was accomplished by a second-order Taylor series expansion. The central grid point was



a. Nearest-neighbor surface S

b. Next-nearest-neighbor surface S'

Figure 5. Surfaces S and S' as defined for the three dimensional-surface algorithm

defined as a local origin, and the expansion was performed about this origin. The resulting surface equations were developed as described in the following paragraphs.

21. Let the equation $z = f(x,y)$ represent the actual terrain surface, where z is the elevation of the grid point with respect to the X-Y Cartesian reference plane. Expanding $f(x,y)$ in a Taylor series to the second order about the local origin yields

$$f(x,y) = z_0 + ax + by + cx^2 + dxy + ey^2 \tag{4}$$

where

z_0 = the elevation of the grid point at the local origin

$$a \equiv \left.\frac{\partial f}{\partial x}\right|_0$$

$$b \equiv \left.\frac{\partial f}{\partial y}\right|_0$$

$$c \equiv 1/2 \left.\frac{\partial^2 f}{\partial x^2}\right|_0$$

$$d \equiv \frac{\partial}{\partial y}\left(\frac{\partial f}{\partial x}\right)\Bigg|_0$$

$$e \equiv 1/2\ \frac{\partial^2 f}{\partial y^2}\Bigg|_0$$

The symbol $|_0$ implies that the value of each partial derivative is to be evaluated at the point $x = y = 0$.

22. Now let two coordinate systems be defined whose origins are common at the grid point of interest. First, the unprimed system (S), (Figure 6a) is defined by the nearest-neighbor grid points, and second, the primed system (S') (Figure 6b) is defined by the next-nearest-neighbor grid points. An equation similar to Equation 4 can be written for the primed system:

$$f(x',y') = z_0 + a'x' + b'y' + c'x'^2 + d'x'y' + e'y'^2 \tag{5}$$

Choose now a grid spacing of D , and apply Equation 4 to each of the four nearest-neighbor elevation values. Four equations result:

$$z_1 = z_0 + aD + cD^2 \tag{6}$$

$$z_3 = z_0 + bD + eD^2 \tag{7}$$

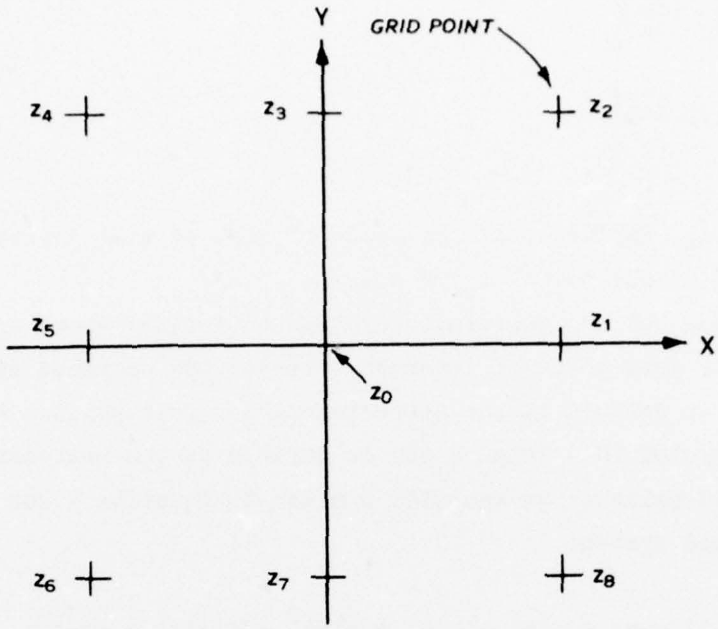
$$z_5 = z_0 - aD + cD^2 \tag{8}$$

$$z_7 = z_0 - bD + eD^2 \tag{9}$$

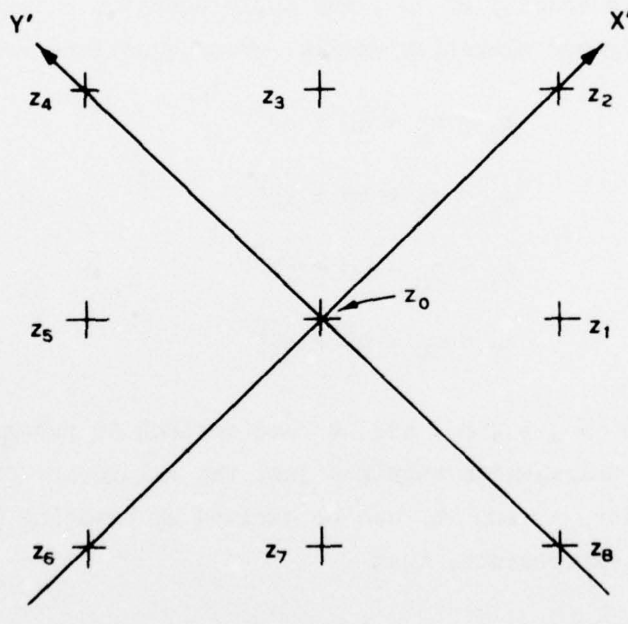
where the values a , b , c , and e are defined in paragraph 20. Since the slope calculation requires just the values of $\partial f/\partial x$ and $\partial f/\partial y$, values for a and b can be derived by treating Equations 6-9 as simultaneous expressions, then

$$a = \frac{(z_1 - z_5)}{2D} \tag{10}$$

and



a. Nearest-neighbor or unprimed system



b. Next-nearest-neighbor or primed system

Figure 6. Taylor series expansion coordinate systems. (Directions conform to a right-handed coordinate system)

$$b = \frac{(z_3 - z_7)}{2D} \tag{11}$$

23. A similar set of four equations can be developed from Equation 5 and the next-nearest-neighbor elevation values. The expansion coefficients a', b', c', and e' can be determined, but as before, only the values of a' and b' are needed. They are expressed as

$$a' = \frac{(z_2 - z_6)}{2\sqrt{2}\ D} \tag{12}$$

and

$$b' = \frac{(z_4 - z_8)}{2\sqrt{2}\ D} \tag{13}$$

24. Before the maximum derivatives with respect to x and y could be determined, it was necessary to express Equations 12 and 13 in terms of the unprimed coordinates. This was accomplished by transforming these equations by a simple 45-deg* rotation.

25. A summary of the partial derivatives expressed in Equations 10 and 11 and the transforms of Equations 12 and 13 are presented in Table 1. If the grid point to be evaluated was a map boundary point, it was necessary to generate pseudo-elevation values before the partial derivatives in Table 1 could be calculated. These pseudo-elevation values were obtained by reflecting inner grid elevation values through the map boundary point to corresponding pseudo-grid locations outside the boundary.

Testing of Algorithms

Generation of terrain surfaces

26. To compare the three algorithms in a consistent and unbiased way, it was necessary to generate controlled elevation grid arrays that

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units and metric (SI) units to U. S. customary units is presented on page 5.

could be easily modified to represent a variety of terrain features and at the same time have the slope and aspect angles known precisely at any given location. To do this, three mathematical surfaces were developed, which had the form $z = f(x,y)$, where z was the elevation value and $f(x,y)$ was a completely continuous function in x and y. Continuity implied the existence of precisely determinable slope values for any given coordinate location of x and y. The three surfaces generated were named cuspfunction, cosfunction, and deltafunction after their analytic functional forms (Figure 7).

27. Cuspfunction surface. The cuspfunction surface was generated by the exponential form

$$z = Be^{-Ar} \tag{14}$$

where A and B are adjustable parameters. The scalar r is assigned the magnitude of the radius vector $\vec{r} = (x - x_0)\hat{i} + (y - y_0)\hat{j}$, where x_0 and y_0 are convenient grid coordinates for the origin of the radius vector $\vec{r}$. Figure 7a shows a three-dimensional perspective plot of this surface.

28. Cosfunction surface. The cosfunction surface was generated by a superposition of cosine functions and is given by

$$z = A \cos \frac{2\pi x}{T_x} + B \cos \frac{2\pi y}{T_y} + |A| + |B| \tag{15}$$

where

A = amplitude in the x direction

B = amplitude in the y direction

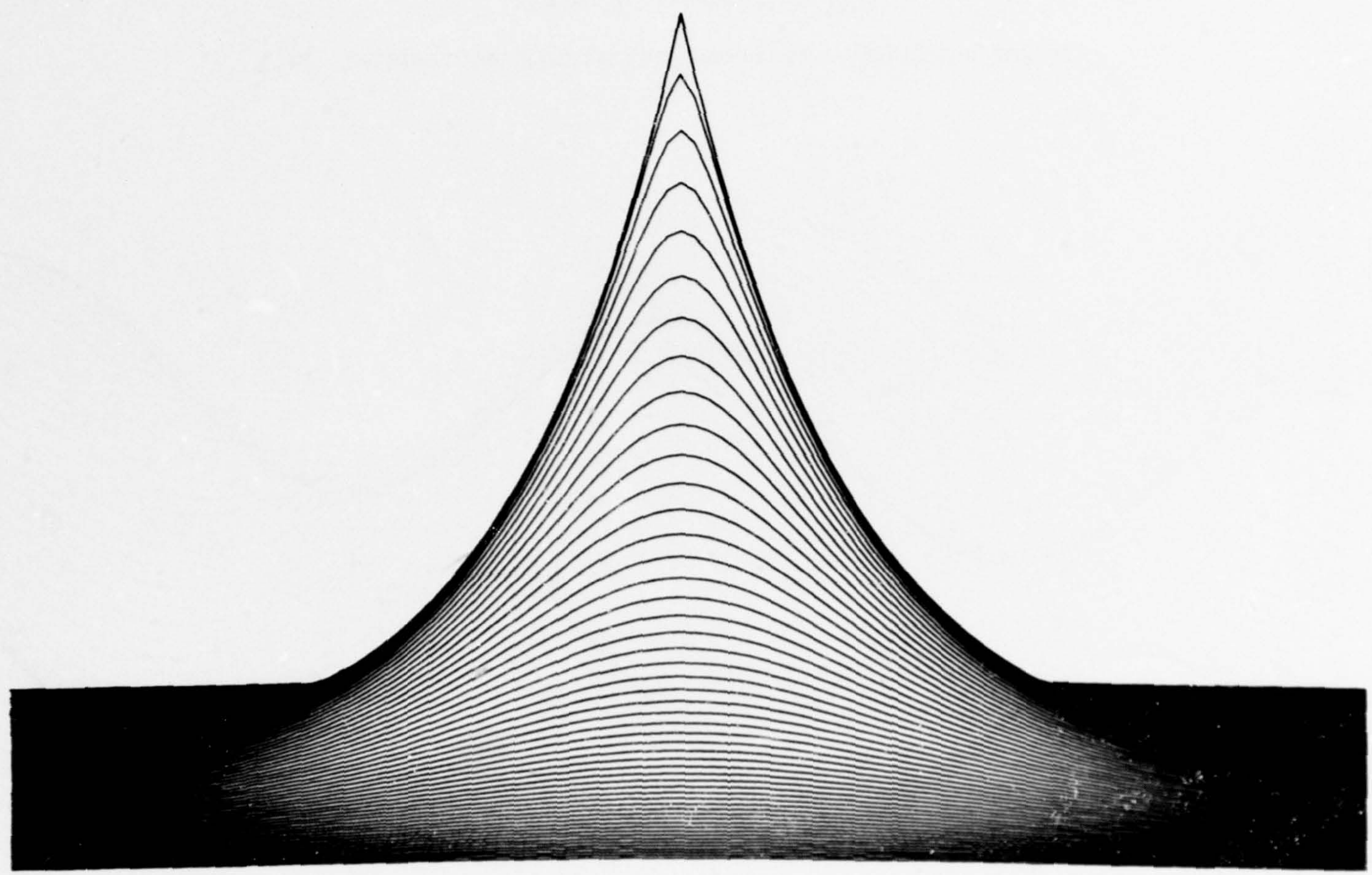
T_x = periodicity factor in units of x

T_y = periodicity factor in units of y

Figure 7b presents a perspective plot of this surface.

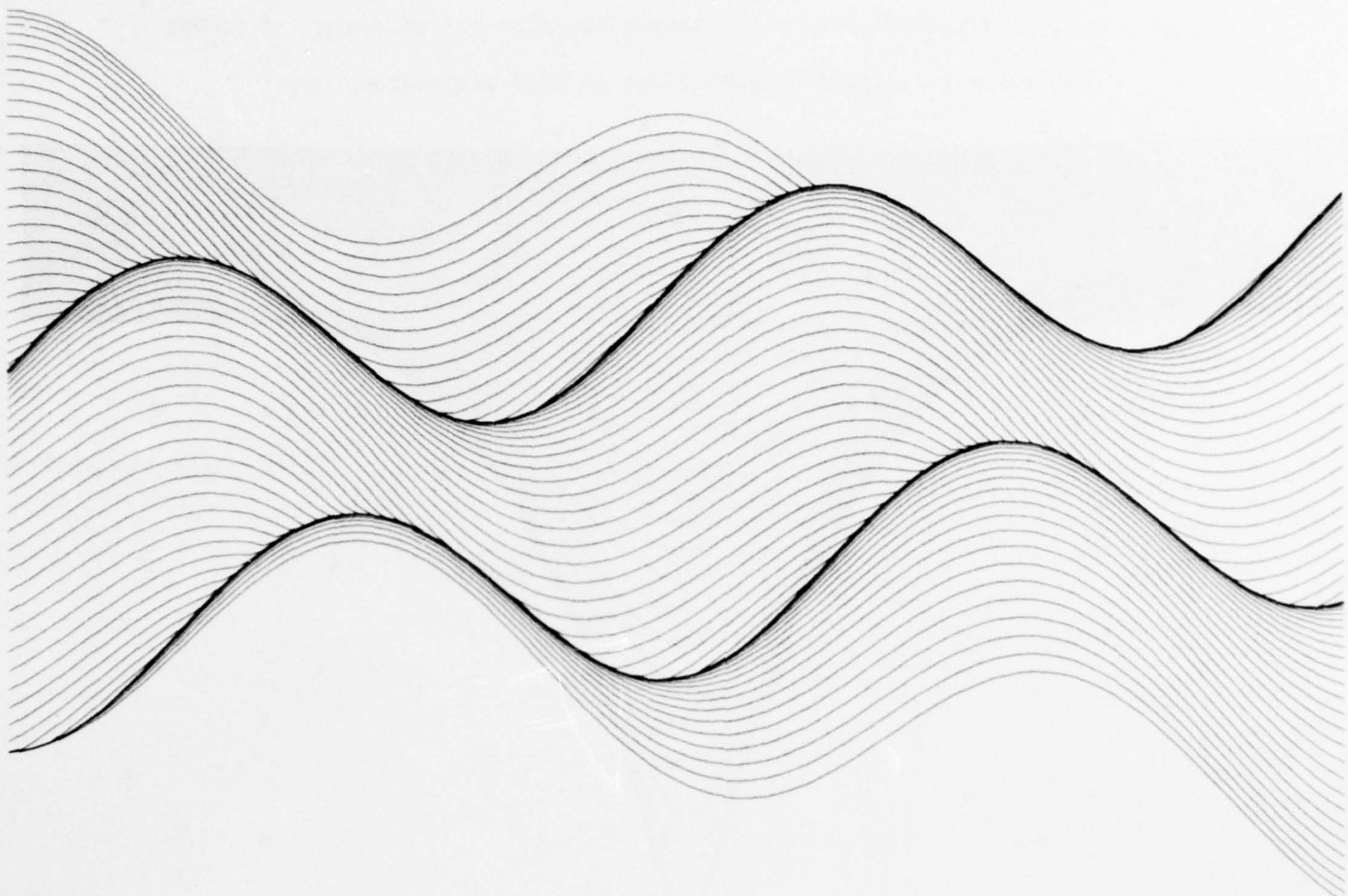
29. Deltafunction surface. The deltafunction surface was expressed in its analytical form as

$$z = \frac{A \sin(2\pi r/T)}{r} + z_0 \tag{16}$$



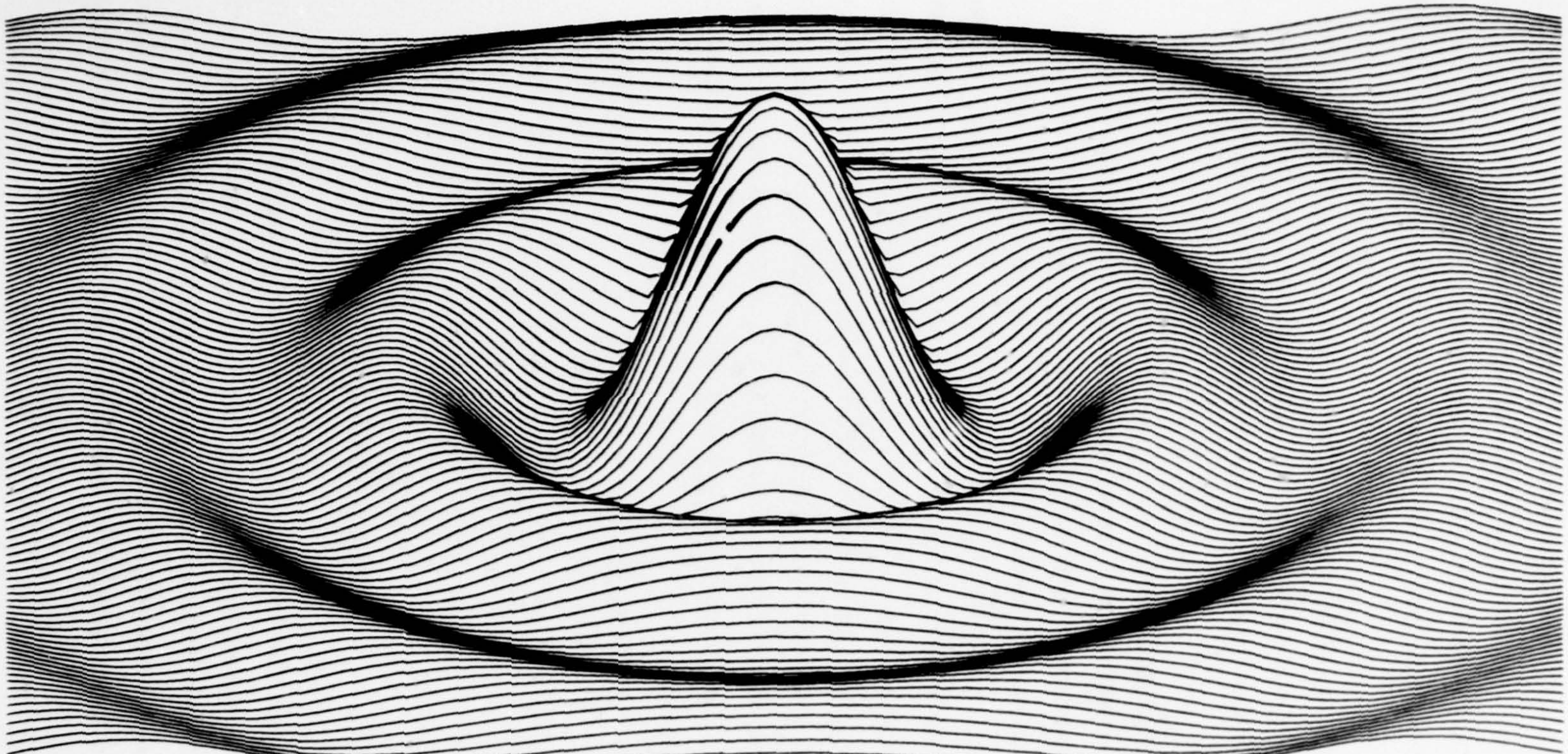
a. Perspective plot of the generated cuspfunction surface

Figure 7. Mathematical surfaces generated to test algorithms (sheet 1 of 3)



b. Perspective plot of the generated cosfunction surface

Figure 7 (sheet 2 of 3)



c. Perspective plot of the generated deltafunction surface

Figure 7 (sheet 3 of 3)

where the function is characterized by its amplitude A, periodicity T, and the scalar magnitude of the radius vector $\vec{r} = (x - x_0)\hat{i} + (y - y_0)\hat{j}$. The reference plane determined by z_0 was set so that all z values would be positive. Figure 7c shows a perspective plot of this surface.

30. Equations 14-16 are continuous and differentiable; therefore, exact analytical expressions for the slope and aspect angles could be obtained. With this capability, the slope algorithms could be compared and evaluated.

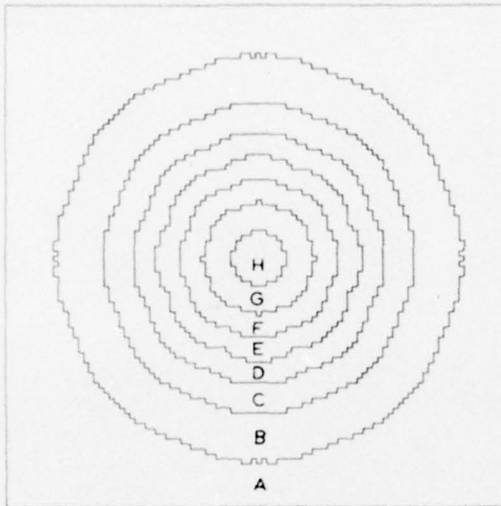
Testing the slope algorithms

31. An elevation grid array was generated from the equations for the three test surfaces. For testing purposes, slope class ranges were set at 10-deg increments beginning with 0 (i.e. 0 to <10 deg, 10 to <20 deg, 20 to <30 deg, etc.), and an array of classed slope values was generated from the elevation data. Slope classes were delineated by the drum plot subroutine (see paragraphs 56 and 57). Figures 8, 9, and 10 show the boundaries of the delineated slope classes for the cuspfunction, cosfunction, and deltafunction surfaces, respectively, together with boundaries of the slope classes determined by differential calculus (exact values). The classes are labeled according to the ranges in the following tabulation:

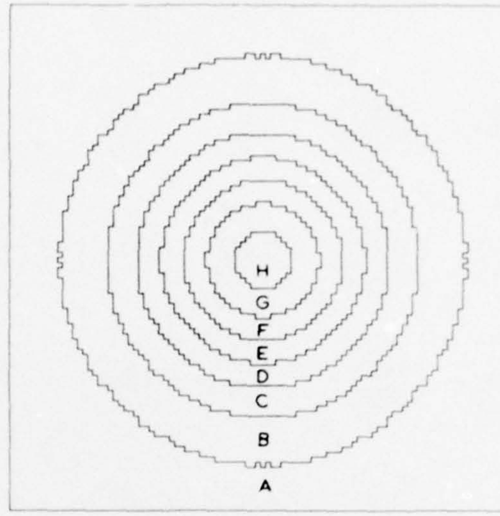
Class	Range, deg	Class	Range, deg
A	0 to <10	E	40 to <50
B	10 to <20	F	50 to <60
C	20 to <30	G	60 to <70
D	30 to <40	H	70 to <80

Evaluation of Algorithms

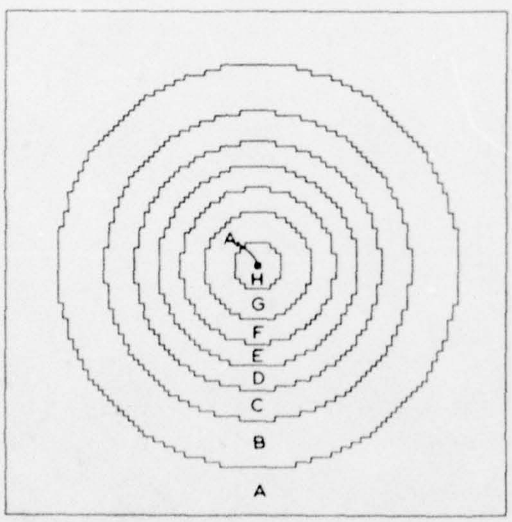
32. Although the boundaries between slope classes for all algorithms displayed the same trends and lay very close to the boundaries determined by differential calculus (exact values), the boundaries generated by the surface algorithm clearly coincided more closely with those determined by differential calculus. Not only did the boundaries



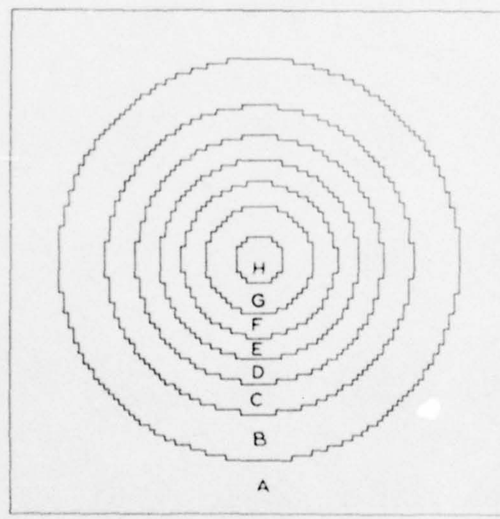
a. Determined by the vector algorithm



b. Determined by the plane algorithm

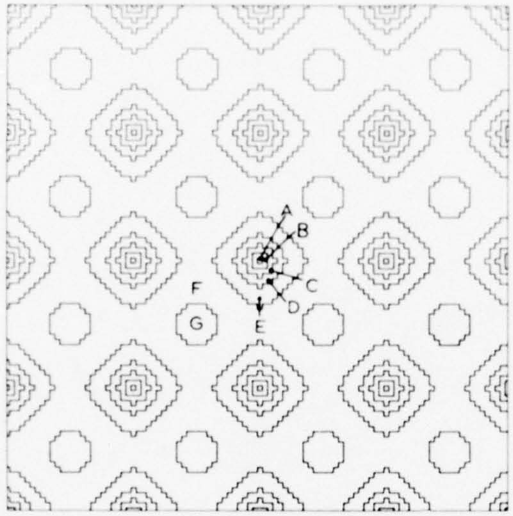


c. Determined by the surface algorithm

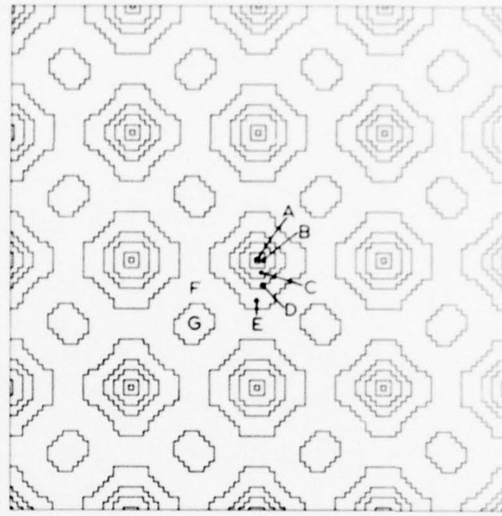


d. Determined by differential calculus

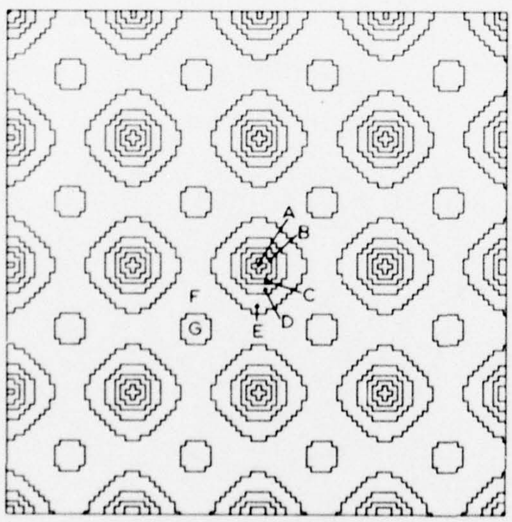
Figure 8. Comparison of slope class delineation boundaries for the surface cuspfunction



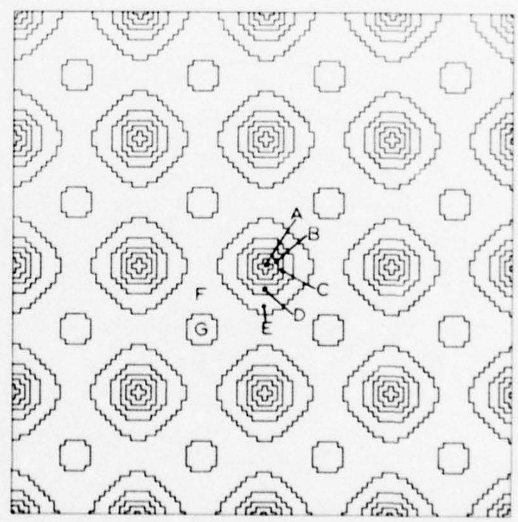
a. Determined by the vector algorithm



b. Determined by the plane algorithm

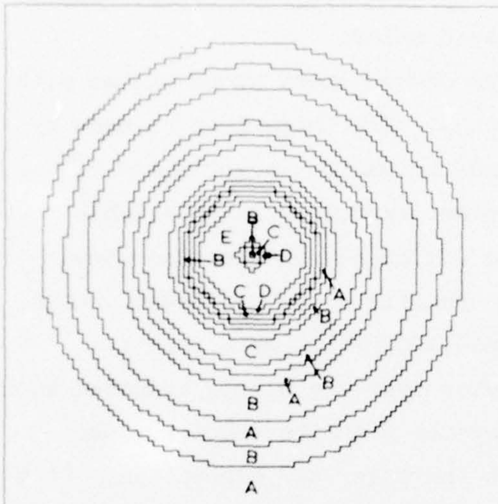


c. Determined by the surface algorithm

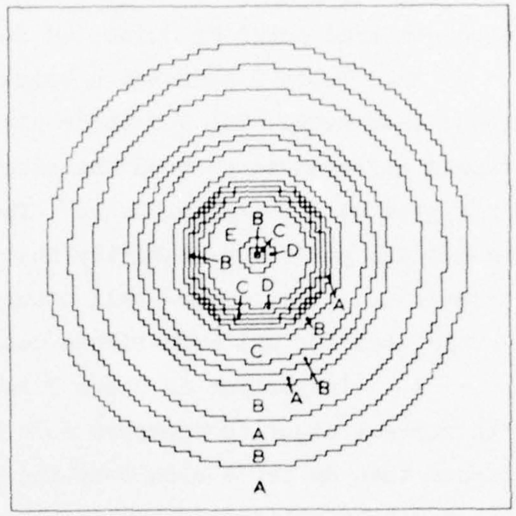


d. Determined by differential calculus

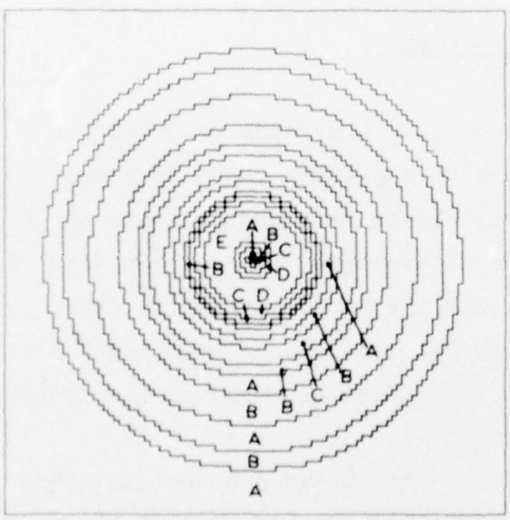
Figure 9. Comparison of slope class delineation boundaries for the surface cosfunction



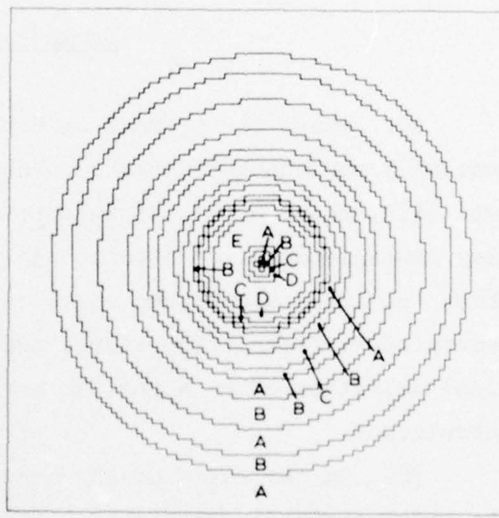
a. Determined by the vector algorithm



b. Determined by the plane algorithm



c. Determined by the surface algorithm



d. Determined by differential calculus

Figure 10. Comparison of slope class delineation boundaries for the surface deltafunction

coincide more closely, but also the slope values calculated with the surface algorithm were in better agreement with the exact slope values when compared point by point, as discussed below.

33. Table 2 presents a comparison of the exact slope values with those calculated with the three algorithms. The comparison is made by taking differences between the exact and the various algorithmic values on a grid point-by-point basis. The values expressed in this table represent the percent probability that the difference between the algorithmic and exact slopes fell within a specific slope difference range. Arrays used for all comparisons contained 100 by 100 grid points.

34. Inspection of Table 2 indicates that the slopes computed with the surface algorithm compare more favorably with the exact surface slopes than do the slopes computed with the other two algorithms. From the point-by-point differences computed, 93.8 percent fell within the difference range of 0 to <1 deg, meaning that 93.8 percent of all surface algorithm values were within 1 deg or less of the exact values, and the remaining surface algorithm values were between 1 and 2 deg.

Summary of Results

35. Since the primary objective of this study was to develop a generally applicable automated procedure to construct baseline slope data (i.e. slope maps), to support a variety of data requirements at Army installations, no attempt was made to evaluate the accuracy with which the three algorithms would calculate the aspect angles of the generated surfaces. Therefore, the only criteria for determining the final selection of an algorithm were the cost and accuracy of the slope calculation.

36. On the basis of the comparisons made above and the fact that the total computer computational cost did not differ significantly from one algorithm to the next, the surface algorithm was selected as the "best" algorithm for constructing baseline slope maps and was, therefore, incorporated into the automated procedure.

PART III: AN AUTOMATED PROCEDURE FOR CONSTRUCTING SLOPE MAPS

37. A general flow diagram delineating the functional steps in the automated procedure (computer program) for constructing slope maps is presented in Figure 11. In the operation of the computer program, named SLOPEMAP, the program basically accepts topographic data prepared in advance, calculates and classes slope values, and then processes these data into optional forms of output. A computer listing of SLOPEMAP and a glossary of program variables are presented in Volume II of this report.

Topographic Input Data

38. Two acceptable forms of topographic data can be input to SLOPEMAP, elevation or vector data. The basic elevation data needed can be obtained (see paragraphs 6 and 7) from field survey data, aerial photography, or topographic maps. The alternative vector form of inputting topographic data is provided to reduce the amount of computer processing time during subsequent reclassification runs on the same terrain data. For example, if a given terrain surface is to be classed by different slope class ranges (see paragraphs 48-50) several times, it is faster and cheaper to let SLOPEMAP generate a vector grid array (see paragraphs 62 and 63) during the first run with an elevation grid array and then use the vector grid array instead of the elevation data in all subsequent runs. This prevents the computer from having to duplicate numerous identical calculations. The general instructions for preparing these two input forms are described below.

Elevation data

39. The topographic surface must be represented by an elevation grid array (Figure 12), each element of which is the elevation (in metres) of the topographic surface at that grid position. The two planimetric dimensions are designated X and Y , and the elevation of the surface Z is designated as the vertical dimension for the

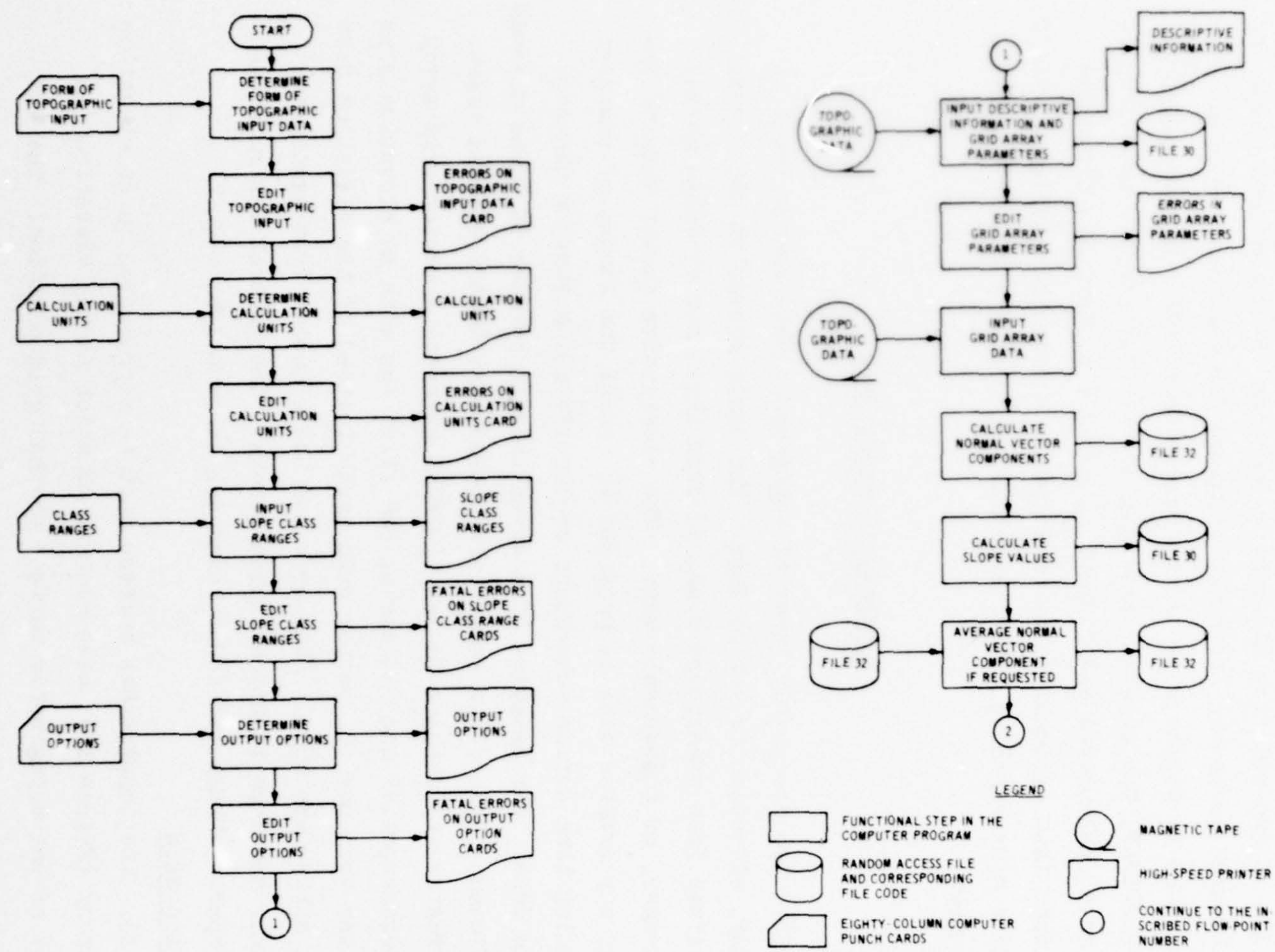


Figure 11. Flow diagram of the automated procedure for constructing slope maps (sheet 1 of 2)

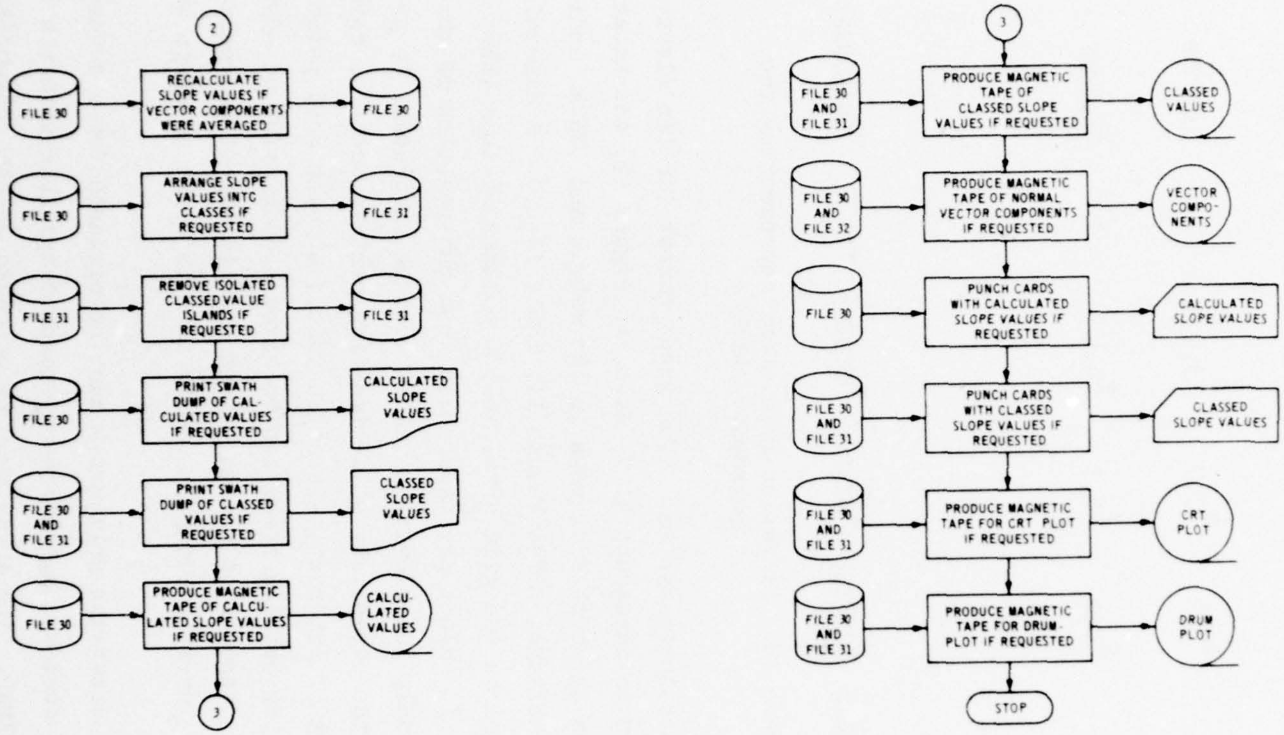


Figure 11 (sheet 2 of 2)

$$
\begin{matrix}
Z_{1,1} & Z_{1,2} & Z_{1,3} & Z_{1,4} & \cdots & Z_{1,NXRE} \\
Z_{2,1} & Z_{2,2} & Z_{2,3} & Z_{2,4} & \cdots & Z_{2,NXRE} \\
Z_{3,1} & Z_{3,2} & Z_{3,3} & Z_{3,4} & \cdots & Z_{3,NXRE} \\
Z_{4,1} & Z_{4,2} & Z_{4,3} & Z_{4,4} & \cdots & Z_{4,NXRE} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
Z_{NYRE,1} & Z_{NYRE,2} & Z_{NYRE,3} & Z_{NYRE,4} & \cdots & Z_{NYRE,NXRE}
\end{matrix}
$$

Figure 12. Elevation grid array representing the topographic surface

rectilinear coordinate system. (The input format for the elevation grid arrays is given in paragraph 41.) Also, in Figure 12, the notation NYRE indicates the number of rows in the matrix and NXRE indicates the number of columns. (See Volume II, Table II-2.) A dimension statement restricts the grid array to 500 columns or less ($NXRE \leq 500$). Since X and Y values are understood from the position of the element in the array, only the elevation values need be recorded. To provide the user with the capability of designating certain areas as being outside an area of interest, elevation values at each grid point corresponding to the outside areas can be given a code value of -999. This will cause the computer to assign values of 0 to the slope vector components and to insert a blank character into the classed slope value array.

40. The elevation grid array must be prepared for a sequential computer file, such as magnetic tape, to be compatible with the input format of SLOPEMAP. The array must be preceded on the sequential file by appropriate identification records, which must include the following:

a. Identification number. The user must provide an integer identification number not to exceed 10 digits.

b. Data scale. The scale of the elevation data (DATASC) given in fractions of a metre (e.g., 0.01 implies that the elevation values on the sequential file are in centimetres).

c. Grid size. The number of rows (NYRE) and columns (NXRE) defining the grid size in integer units.

d. Grid spacing. The spacing (D) between the elements of the array is constant within any one grid array, but the value must be specified by the user. Values are typically chosen in the range of 25 to 100 m.

41. After the identification records are placed on the sequential file, the elevation grid array must follow one row at a time, with each row treated as a single record. Thus, the final file contains the following records (the input format for each record is provided in the comment statements below):

Record	Comments
1	Reserved for user's identification number. FORMAT (I10, 122X)
2-7	Reserved for user's descriptive information. Usually contains file identification and the location and description of the site. FORMAT (22A6)
8	Contains the variable values of DATASC , NXRE , NYRE , and D , respectively. FORMAT (F5.2, 5X, 2I6, F6.1)
9 through (NYRE + 8)	Contains elevation values (binary integers). The number of records from 9 through (NYRE + 8) is equal to the number of rows in the grid elevation array. Each record contains the same number of elevation values as there are columns in the array

42. Magnetic tapes of digital elevation data can be prepared at the Defense Mapping Agency Topographic Center (DMATC)* or, in exceptional instances, at the WES. An index of currently available DMATC large-scale (1:24,000-1:62,500) digital terrain elevation data on

* Defense Mapping Agency Topographic Center, 6500 Brooks Lane, Washington, D. C. 20315.

military installations in the United States is contained in Table 3. However, the DMATC data tapes are not directly compatible with SLOPEMAP. Therefore, an interface program (available from the WES) must first be used to reformat the DMATC tapes before these data are acceptable to SLOPEMAP. The cost of preparation of data tapes depends on the size of the area to be digitized, the topographic complexity of the area of interest, and the nature of the primary data source (i.e., field survey data, existing topographic maps, or aerial photographs). Inquiries concerning time and cost estimates can be addressed to the DMATC or the WES.

Vector data

43. As stated in paragraph 37, the representation of the topographic surface can also be input to SLOPEMAP in the form of components of the slope vectors $\vec{N}$ (Equation 1). Instead of elevation values representing each grid location, the vector components $f_x \equiv -\partial f/\partial x$ and $f_y \equiv -\partial f/\partial y$ represent the topographic surface at each grid location in the array (Figure 13).

$$
\begin{array}{ccccc}
(f_x,f_y)_{1,1} & (f_x,f_y)_{1,2} & (f_x,f_y)_{1,3} & \cdots & (f_x,f_y)_{1,NXRE} \\
(f_x,f_y)_{2,1} & (f_x,f_y)_{2,2} & (f_x,f_y)_{2,3} & \cdots & (f_x,f_y)_{2,NXRE} \\
(f_x,f_y)_{3,1} & (f_x,f_y)_{3,2} & (f_x,f_y)_{3,3} & \cdots & (f_x,f_y)_{3,NXRE} \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
(f_x,f_y)_{NYRE,1} & (f_x,f_y)_{NYRE,2} & (f_x,f_y)_{NYRE,3} & \cdots & (f_x,f_y)_{NYRE,NXRE}
\end{array}
$$

Figure 13. Vector grid array representing the topographic surface

44. A sequential computer file (e.g. magnetic tape) must be prepared to make the vector component data acceptable to SLOPEMAP. The identification and vector grid array records must be placed on the

sequential file by exactly the same procedure previously discussed for the elevation grid array data (see paragraphs 40 and 41). The one exception is that, instead of single elevation values, records 9 through (NYRE + 8) contain vector component pairs of values as binary integers multiplied by 100,000. The number of records from 9 through (NYRE + 8) again equals the number of rows in the grid array, but each record contains twice the number of values as there are columns in the array.

Card Input Data

45. The execution of SLOPEMAP is controlled by the card input data. These cards are prepared with information pertaining to the form of topographic input data, calculation units, slope class ranges, and the desired output options. Each type of card input is discussed in this section and examples are shown.

Form of topographic input data

46. The first step in the execution sequence of SLOPEMAP (Figure 11) is to establish the form of topographic input data to be used, i.e. elevation grid array values or vector component values. The selection is made by entering either the term ELEVAT or VECTOR on the first input card (Figure 14a).

Calculation units

47. The second input requirement is to establish the units in which the slope values are to be calculated, i.e., slope values expressed in degrees or tangent values of the angle. All subsequent input and output data are then in the chosen units. The selection is made by entering into the second card either the term DEGREE or TANGEN (Figure 14b).

Slope class ranges

48. The slope class ranges are read into the program on succeeding input cards. The parameters punched into card 3 are the lower and upper bounds of the first slope class range. Each succeeding pair of values encountered on cards 4, 5, 6, etc., define the second, third, fourth, etc., slope class ranges (Figure 14c). The third card should

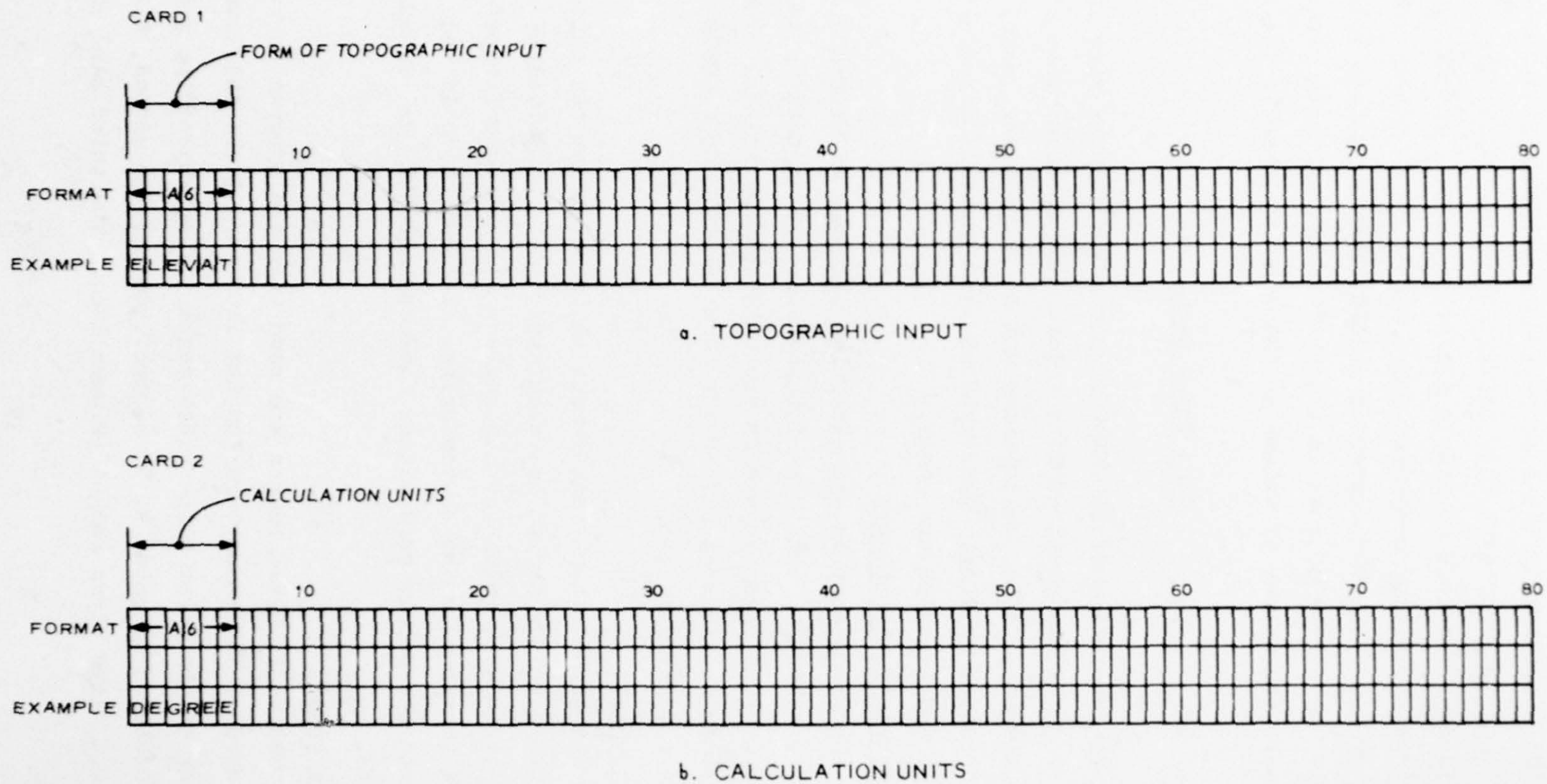
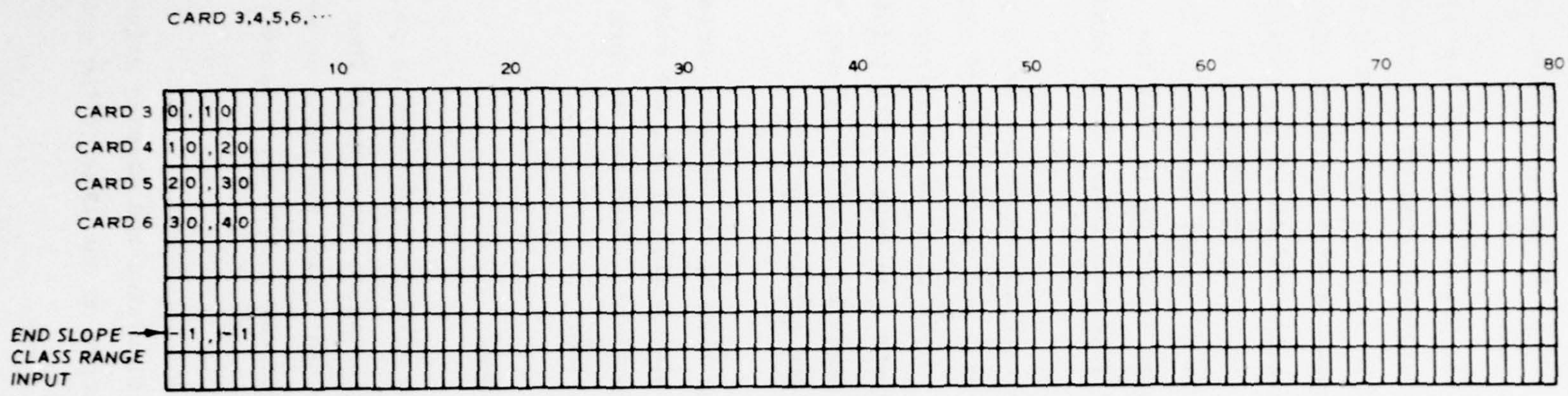
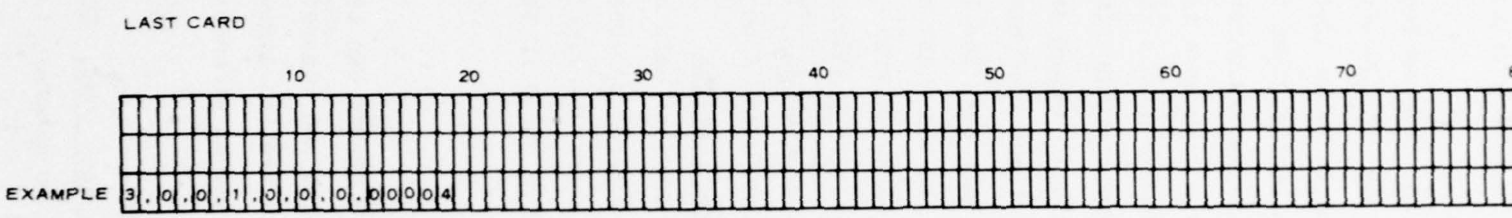


Figure 14. Formats of cards used as input data for SLOPEMAP (sheet 1 of 2)



NOTE: CLASS RANGES GIVEN ARE 0° - <10°, 10° - <20°, 20° - <30°, AND 30° - <40°

c. SLOPE CLASS RANGES



d. OUTPUT OPTIONS

Figure 14 (sheet 2 of 2)

contain two negative values separated by commas if no class values are to be output.

49. The program format interprets all input data cards for slope class range by a "list-directed" format statement (statement 1 of the main program in Table II-1, Volume II). The list-directed form of entering data implies that the number and types of list variables directly determine the way in which the computer assigns values to the variables. This offers a much more flexible form of inputting the slope class ranges as compared to a fixed columnar form of format statement. The one requirement of the list-directed form of inputting is that the variable values on each card be separated from each other by at least one blank column or a comma.

50. Note that the last class range card in Figure 14c has a pair of negative values. Any negative number will end the reading of classed values and cause control to be passed on to the class range editor. The editor checks for possible errors and outputs a message to the printer if errors are detected. The last card containing negative values is still required even if no classed values are to be output.

Desired output options

51. The last data card (Figure 14d) read by the program contains the output control options. Table 4 contains a list of all the control values and short descriptions of their functions. Each output form is explained more fully in the following section.

Output of SLOPEMAP

52. SLOPEMAP can be directed by the output option card to process the calculated and classed slope information in one or more of four modes. This section discusses the four output modes available as well as two additional processing options of the calculated and classed slope data.

Output modes

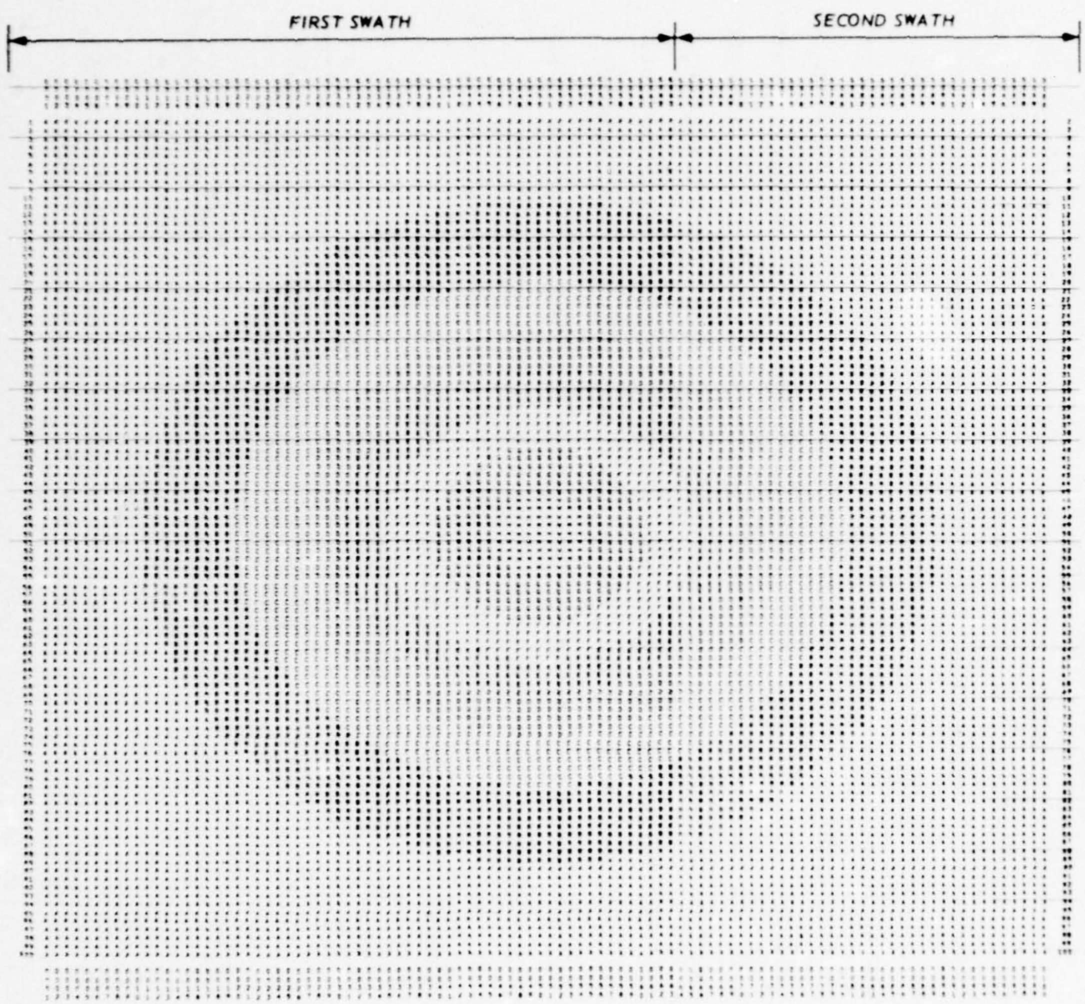
53. Swath dump. The rows of the calculated and classed value arrays are, in general, too long to be output on one line of the printer.

The program solves this by calling the subroutines CALSWH or CLSSWH to print vertical swaths of values. Each swath corresponds to a swath taken from the calculated or classed arrays and is restricted to a maximum of 132 characters per line. After the first swath has been written by the printer, the program begins the next swath and continues until the entire set of array elements has been printed. For display purposes, the separate swaths can be laid side by side and assembled manually to form a mosaic slope map of computer calculated or classed slope values as shown in Figure 15.

54. Magnetic tapes. The user has the option of storing calculated or classed slope values onto magnetic tape in binary integer form. The program calls subroutine TAPCAL to output a tape of calculated values or subroutine TAPCLS to output a tape of classed values. The calculated slope values are recorded on tape following the descriptive information copied from the input topographic data tape. Classed values are recorded following the descriptive information, the number of classes (NCLAS), and the previously selected class ranges. Because of inherent round-off errors during integer arithmetic performed by the computer, SLOPEMAP was programmed to calculate slope values at a scale 100 times greater than actual values for degree units and 100,000 times greater than actual values for tangent units. Therefore, the calculated values output to magnetic tape represent slope values multiplied by these amounts. The tapes contain the following records (the output format for each record is provided in the comment statement below):

a. Calculated slope values.

Record	Comments
1	Contains the identification number copied from the input topographic data file. FORMAT (I10,122X)
2-7	Contains the descriptive information copied from the input topographic data file. FORMAT (22A6)
8	Contains variable values DATASC , NXRE , NYRE , and D , respectively. FORMAT (F5.2,5X,2I6,F6.1)



LEGEND

CLASS	RANGE, DEG
A	0 - < 10
B	10 - < 20
C	20 - < 30
D	30 - < 40
E	40 - < 50
F	50 - < 60
G	60 - < 70
H	70 - < 80

Figure 15. An assembled swath dump of classed values for a generated cuspfunction surface

Record	Comments
9 through (NYRE + 8)	Contains calculated slope values (binary integers). The number of records from 9 through (NYRE + 8) is equal to the number of rows in the original input topographic grid array. Each record contains the same number of slope values as there were columns in the input array. Each slope value has been multiplied by either 100 (for degrees) or 100,000 (for tangent of of the angle)

b. Classed slope values.

Record	Comments
1	Contains the identification number copied from the input topographic data file. FORMAT (I10,122X)
2-7	Contains the descriptive information copied from the input topographic data file. FORMAT (22A6)
8	Contains variable values of DATASC , NXRE , NYRE , and D , respectively. FORMAT (F5.2,5X,2I6,F6.1)
9	Contains the number of slope class ranges NCLAS (in binary)
10 through (NCLAS + 9)	Contains the lower and upper bounds of each class range. The number of records from 10 through (NCLAS + 9) is equal to the number of slope class ranges. Each record contains a pair of numbers (binary)
(NCLAS + 10) through (NYRE + NCLAS + 9)	Contains classed slope values (binary integers). The number of records (NCLAS + 10) through (NYRE + NCLAS + 9) is equal to the number of rows in the original input topographic grid array. Each record contains the same number of classed values as there are columns in the input array

55. Punch cards. Calculated or classed values can be output into punched cards by the subroutines CRDCAL and CRDCLS , respectively. Descriptive information contained on the elevation data tape is first punched by the selected subroutine. The calculated values follow the descriptive information in the case of CRDCAL ; but in the case of

CRDCLS , the number of classes and class ranges are punched prior to the classed values being output in integer form. The card decks contain the following information (the output format for each card is provided in the comment statements below):

a. Calculated slope values.

Card	Comments
1	Contains the identification number copied from the topographic data file and a card sequence number. FORMAT (I10,60X,I10)
2-7	Contains the descriptive information copied from the input topographic data file and a card sequence number. FORMAT (11A6, 4X,I10)
8	Contains variable values DATASC , NXRE , NYRE , D , and a card sequence number. FORMAT (F5.2,5X,2I6,F6.1,42X,I10)
9 through NYRE(NXRE/7) + 8 or NYRE (NXRE/7 + 1) + 8	Contains calculated slope values and a card sequence number. The maximum number of calculated slope values per card is 7. If (NXRE/7) is an integer value, then the total number of cards containing calculated values equals NYRE(NXRE/7) . However, if (NXRE/7) is not an integer value, then the number of cards containing calculated value equals NYRE(NXRE/7 + 1) . Each output slope value is either 100 (for degrees) or 100,000 (for tangent of the angle) times greater than their actual magnitudes. FORMAT(10I7,I10)

b. Classed slope values.

Card	Comments
1	Contains the identification number copied from the input topographic data file and a card sequence number. FORMAT (I10,60X,I10)
2-7	Contains the descriptive information copied from the input topographic data file and a card sequence number. FORMAT (11A6,4X,I10)
8	Contains variable values DATASC , NXRE , NYRE , D , and a card sequence number. FORMAT (F5.2,5X,2I6,F6.1,42X,I10)

Card	Comments
9	Contains the number of slope class ranges (NCLAS) and a card sequence number. FORMAT (I10,60X,I10)
10 through (NCLAS + 9)	Contains lower and upper bounds of each class range and a card sequence number. The number of cards from 10 through (NCLAS + 9) is equal to the number of slope class ranges. Each card contains three numbers. FORMAT (2F10.3,50X,I10)
(NCLAS + 10) through NYRE(NXRE/35) + (NCLAS + 9) or NYRE(NXRE/35 + 1) + (NCLAS + 9)	Contains classed slope values and a card sequence number. The maximum number of classed slope values per card is 35. If (NXRE/35) is an integer, then the total number of cards containing classed values equals NYRE(NXRE/35). However, if (NXRE/35) is not an integer, then the number of cards containing classed values equals NYRE(NXRE/35 + 1) . FORMAT (35I2,I10)

56. Drum and CRT plots. If the user wants a graphic display of the boundaries between delineated classed values, he must choose the option to output either a drum plot or a CRT plot. Each outputs a slope map with lines separating different classed values. Figures 8-10 show example drum plots of slope class boundaries. Descriptive information contained on the input topographic data tape is also plotted.

57. The scale for outputting the drum plot must be set so that the X and Y dimensions of the plot, XLEN and YLEN , do not exceed 64 and 24 in. (limitation of WES drum plotter), respectively. Therefore, the user must carefully select the drum plot scale value, PLSCL , before running the program. The following set of equations can be used to check selected plot scales to ensure that XLEN and YLEN do not exceed their limits:

$$\text{XLEN (inches)} = (\text{PLSCL})\times(39.37007)\times(\text{D})\times(\text{NXRE}-1)$$

$$\text{YLEN (inches)} = (\text{PLSCL})\times(39.37007)\times(\text{D})\times(\text{NYRE}-1)$$

where

D = elevation grid spacing in metres

NXRE
NYRE = number of grid points along the X and Y axes, respectively

The CRT plot does not require a scale input value but generates its own at run time. The program selects and outputs a scale that will allow the CRT plot to be output as large as possible, but within its maximum size of 17 by 11 in. (limitation of WES CRT plotter). This feature makes available a reliable, inexpensive, and quick graphic aid for use during the early stages of slope map construction. After output needs have been established, the more costly, but more accurate, drum plot option can be used.

Additional processing options

58. Smoothing. SLOPEMAP offers the capability of further processing the calculated values and classed values in two additional ways before output. The decision to use one or both ways is made on the output option card in card field 5 (Table 4 and Figure 14d).

59. If card field 5 contains a 0, no further processing will be performed on either the calculated values or classed values. If the fifth position contains a 1, the subroutine SMOOTH is called after the program finishes calculating slope values. This routine calculates an average X component and Y component from the slope vectors surrounding a given grid point. Included in the average are the nearest-neighbor and the next-nearest-neighbor slope vector components. The slope components of the grid point itself are excluded. The average components are then used to calculate a new slope value for the given grid point, and this new value permanently replaces the old one. The process has the effect of smoothing or averaging out rapid slope changes.

60. If the fifth column contains a 2, the subroutine ISLAND is called after the calculated slope values have been classed. This routine removes isolated classed values from the classed value array. For a given grid point, this subroutine examines the nearest and next-nearest neighbors to determine if the given point is isolated, i.e. no equal class contiguous to it. If the isolated value does not differ by more than one class value from its neighbors, it is replaced by the closest class value. If the isolated value falls equally between a

higher and a lower neighbor value, it takes the lower value. The subroutine does not alter the isolated value if its neighbors differ by two or more classed values. The removal of isolated islands existing in the classed value array can have the effect of removing features that would result in poor delineation of the slope regime of the topographic surface.

61. Both of the two options can be selected to operate on the data sequentially by choosing a value of 3 for the fifth card field of the output option card. The subroutine SMOOTH will be executed prior to subroutine ISLAND .

62. Vector components. The slope algorithm makes use of the X and Y components of the slope vector to calculate slope values. If directional information is needed for later use (e.g. as a subsequent input tape to SLOPEMAP), then the vector components can be output onto magnetic tape. Since the slope vector components are calculated and stored within the computer at 100,000 times their actual magnitudes as was similarly done for the slope values (see paragraph 54), the component values are output to magnetic tape at this scale.

63. The three-dimensional vector $\vec{N}$ can be reconstructed to represent the slope vector (or vector normal to the surface) at any given grid location (see paragraph 14). The slope vector is then written

$$\vec{N} = (XCOMP/100000)\ \hat{i} + (YCOMP/100000)\ \hat{j} + \hat{k}$$

where $XCOMP \equiv 100000(-\partial f/\partial x)$ and $YCOMP \equiv 100000(-\partial f/\partial y)$ are the vector components stored on the slope vector output tape. The tape contains the following records (the output format for each record is provided in the comment statements below):

Record	Comments
1	Contains the identification number copied from the input topographic data file. FORMAT (I10,122X)
2-7	Contains the descriptive information copied from the input topographic data file. FORMAT (22A6)
8	Contains variable values DATASC , NXRE , NYRE , and D , respectively. FORMAT (F5.2,5X,2I6,F6.1)

Record	Comments
9 through (NYRE + 8)	Contains X and Y slope vector component pairs (binary integers). Each component has been multiplied by 100,000. The number of records from 9 through (NYRE + 8) is equal to the number of rows in the grid array, and each record contains twice the number of values as there are columns in the array

Error Messages

64. Error messages are incorporated into the computer program to assist the user in identifying input errors. These error messages are listed below; comment is provided if necessary.

a. "The input topographic data were not specified in an acceptable form. The only choices available to the user are ELEVAT or VECTOR . This error causes immediate program termination. Please correct the input before resubmitting."

b. "The input calculation units have not been properly selected. Only choices are DEGREE or TANGEN . This error causes immediate program termination. Please correct the input before resubmitting."

c. "The number of input slope classes exceeds the present allowed maximum 36. If this is not an error and you think the output graphics will still look reasonable with so many classes, you will have to change the dimension of the variable CLASS and the value of the constant MAXCLASS and resubmit the run."

d. "The class ranges on the input cards should not overlap. This error causes immediate program termination. Please correct the input before resubmitting."

e. "There are duplicate cards in the slope class range input cards. A missing card is suspected. This error causes immediate program termination. Please correct the input before resubmitting."

f. "The class range input cards are out of sequence. This error causes immediate program termination. Please correct the input before resubmitting."

g. "To output a magnetic tape with vector components, the control value on the output option card must be 0 or 1."

h. "The control values appearing in the first three card

fields on the output option card must be in the range 0, 1, 2, or 3. Please correct the output option data card."

i. "The control value for the plot option must be 0, 1, or 2. Please correct the output option data card."

j. "The control value for the smoothing options on the output option card must be 0, 1, 2, or 3. Please correct the output option data card."

k. "No output options have been selected. Please correct the output option data card."

l. "You asked for an output of classed values but did not define class ranges. This error causes immediate program termination. Please correct the input before resubmitting."

m. "You are requesting a drum plot with dimensions greater than 60 × 24 in. (X by Y dimensions). Please recheck your plot option scale."

n. "The grid array of elevations has an insufficient number of data points to perform a slope calculation; the array size must be at least a 4 × 4 matrix."

Job Control Language for SLOPEMAP

65. A complete set of job control language (JCL) cards and an example set of data necessary to run SLOPEMAP on the WES Honeywell CARDIN time-sharing (T/S) system are presented in Figure 16. A detailed description of each card function is provided in the Honeywell reference manuals.[4,5] The Honeywell G-635 T/S system (system release 8 update 3) was used throughout the development of the program. Thus, the JCL cards are necessarily tailored to this system; however, they should still provide guidance in setting up JCL cards or their equivalent for other computer systems such as those that might be available on military installations.

66. It should be noted that a typical run does not require the use of all cards. For example, only the $:USE:DRUM or the $:USE:CRT should be inserted if a drum or CRT plot is requested by the user. The same is true of any of the $:TAPE7: cards and the message cards $:MSG2: following them. Only if output is requested on these devices should these cards be inserted. Also, only one topographic input data

```
10##N
20$:IDENT:USERID,STRUVE
30$:OPTION:FORTRAN
40$:FORTY:OPTZ,NFORM,NLNO
50$:LIMITS:10,40K,,5000
60$:SELECT:USERID/SLOPEMAP
70$:USE:.GTLIT
80$:USE:DRUM
90$:USE:CRT
100$:EXECUTE:DUMP
110$:LIMITS:10,35K,,10000
120$:TAPE7:10,X1D,,(TAPE NUMBER)
130$:PRMFL:10,R,L,USERID/DATAC,R
140$:TAPE7:11,X1D,,(TAPE NUMBER)
150$:TAPE7:20,X2DR,,,,CALCULATED-VALUES
160$:MSG2:SAVE 20,STRUVE,USERID,CALCULATED-VALUES OF SLOPES
170$:TAPE7:21,X3DR,,,,CLASSED-VALUES
180$:MSG2:SAVE 21,STRUVE,USERID,CLASSED-VALUES OF SLOPES
190$:TAPE7:22,X4DR,,,,SLOPE-VECTOR
200$:MSG2:SAVE 22,STRUVE,USERID,SLOPE-VECTOR COMPONENTS
210$:TAPE7:23,X5DR,,,,DRUM-PLOT
220$:MSG2:SAVE 23,STRUVE,USERID,DRUM-PLOT
230$:TAPE7:24,X6DR,,,,CRT-PLOT
240$:MSG2:SAVE 24,STRUVE,USERID,CRT-PLOT
250$:FILE:30,X7R,10R
260$:FILE:31,X8R,10R
270$:FILE:32,X9R,20R
280$:DATA:I*
290#ELEVATION
300#VECTORS
310#DEGREES
320#TANGENT
330#0,10
340#10,20
350#20,30
360#30,40
370#40,50
380#50,60
390#60,70
400#70,80
410#80,90
420#-1,-1
430#3,0,0,0,3,0,0.0012828
440$:ENDJOB
```

Figure 16. Complete set of JCL cards to run SLOPEMAP from a source deck on the Honeywell G-635 system

device is required. Therefore, the unused input file cards (e.g. $:TAPE7: and $:PRMFL:) must be deleted. Correspondingly, in the control data cards, only one form of input topographic data and one type of calculation units should be chosen. A list of file codes and their respective input and output file descriptions are presented in Table 5 to help the user assemble a JCL deck.

67. If a non-WES user of SLOPEMAP cannot provide the function implied by the $:SELECT: card (Figure 16), he should replace this card with the SLOPEMAP source statement cards as listed in Table II-1 of Volume II. For a WES user, the SLOPEMAP program should reside as a binary coded decimal (BCD) file under his user identification number. In both cases, execution follows compilation of the source statements.

68. To avoid the necessity of compilation before every computer run, the WES user can take advantage of an existing magnetic tape that contains a compiled and loadable version of SLOPEMAP. This tape, called a system loadable product tape, was produced by the Honeywell Production Library Generator[6,7,8] and is maintained for WES users. The JCL cards to run this version of SLOPEMAP are presented in Figure 17. The same restrictions with respect to JCL cards still apply with the exception of the $:PRODUCT: card. Should the WES user choose to output either a CRT plot or a drum plot, he must use only a $:PRODUCT: SLOPEC or a $:PRODUCT:SLOPED card. A current tape number corresponding to the system loadable product tape can be obtained by addressing an inquiry to the WES.

69. The SLOPEMAP program is available to any authorized user with a remote terminal, such as personnel at military installations. To obtain authorization, a user must first obtain a WES computer account number and information on accessing the system. Authorization for use of the SLOPEMAP program on the WES computer can be obtained by contacting the WES. Telephone inquiries should be made to the author at commercial telephone 601-636-3111, or AUTOVON 435-1680, extension WES, or FTS 542-3111.

```
10#N
20$:IDENT:USERID,STRUVE
30$:PRODUCT:SLOPEC
40$:PRODUCT:SLOPED
50$:LIMITS:10,35K,,10000
60$:TAPE9:H*,T1D,,(TAPE NUMBER)
70$:TAPE7:10,X1D,,(TAPE NUMBER)
80$:PRMFL:10,R,L,USERID/DATAC,R
90$:TAPE7:11,X1D,,(TAPE NUMBER)
100$:TAPE7:20,X2DR,,,CALCULATED-VALUES
110$:MSG2:SAVE 20,STRUVE,USERID,CALCULATED-VALUES OF SLOPES
120$:TAPE7:21,X3DR,,,CLASSED-VALUES
130$:MSG2:SAVE 21,STRUVE,USERID,CLASSED-VALUES OF SLOPES
140$:TAPE7:22,X4DR,,,SLOPE-VECTOR
150$:MSG2:SAVE 22,STRUVE,USERID,SLOPE-VECTOR COMPONENTS
160$:TAPE7:23,X5DR,,,DRUM-PLOT
170$:MSG2:SAVE 23,STRUVE,USERID,DRUM-PLOT
180$:TAPE7:24,X6DR,,,CRT-PLOT
190$:MSG2:SAVE 24,STRUVE,USERID,CRT-PLOT
200$:FILE:30,X7R,10R
210$:FILE:31,X8R,10R
220$:FILE:32,X9R,20R
230$:DATA:I*
240#ELEVATION
250#VECTORS
260#DEGREES
270#TANGENT
280#0,10
290#10,20
300#20,30
310#30,40
320#40,50
330#50,60
340#60,70
350#70,80
360#80,90
370#-1,-1
380#3,0,0,0,3,0,0.0012328
390$:ENDJOB
```

Figure 17. Complete set of JCL cards to run SLOPEMAP from a system loadable product tape on the Honeywell G-635 system

PART IV: DEMONSTRATION OF THE AUTOMATED PROCEDURE FOR CONSTRUCTING SLOPE MAPS

70. To demonstrate how baseline slope data can be obtained using the program SLOPEMAP, two sites were chosen, one located in the Middle East (Israel) and the other was located at an Army installation (Hunter-Liggett Reservation, California). These sites were selected because they contained two different contour intervals, 20-m (65.6-ft) contours for the Middle East site and 40-ft contours for the Hunter-Liggett site. The map scales of the two sites were 1:50,000 for the Middle East site and 1:25,000 for the Hunter-Liggett site. The approach taken was to choose example outputs from the available optional outputs and then to evaluate them with respect to manually produced slope maps. The procedures for producing slope maps of both sites are discussed and evaluated in the following paragraphs.

Middle East Site (1:50,000 Map Scale)

71. The procedural steps followed to produce slope maps of the Middle East site were to:

- a. Construct input elevation grid array.
- b. Edit and examine elevation grid array.
- c. Select forms of desired output.
- d. Prepare input data and JCL cards necessary to execute SLOPEMAP.
- e. Execute SLOPEMAP.
- f. Construct slope maps from selected output forms.

Site elevation data

72. A topographic map of the selected Middle East site is shown in Figure 18. The northwest corner of the site is 6 km southeast of Nazareth, Israel. The contour interval is 20 m with an occasional supplementary 10-m contour shown in the flatter areas. Each contour line within the 10- by 7-km site was digitized and processed by a WES computer program[3] that generates an elevation grid array. The spacing

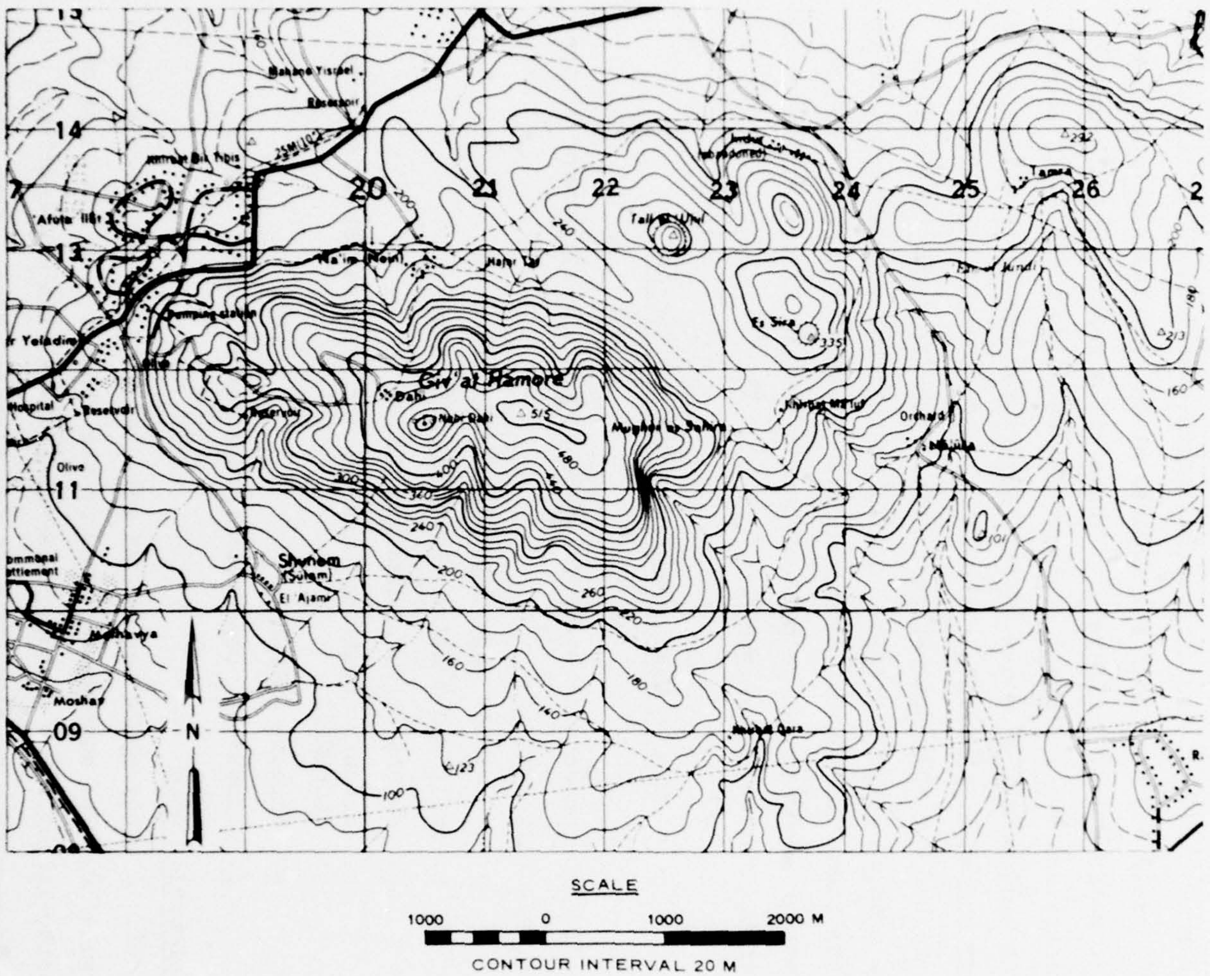


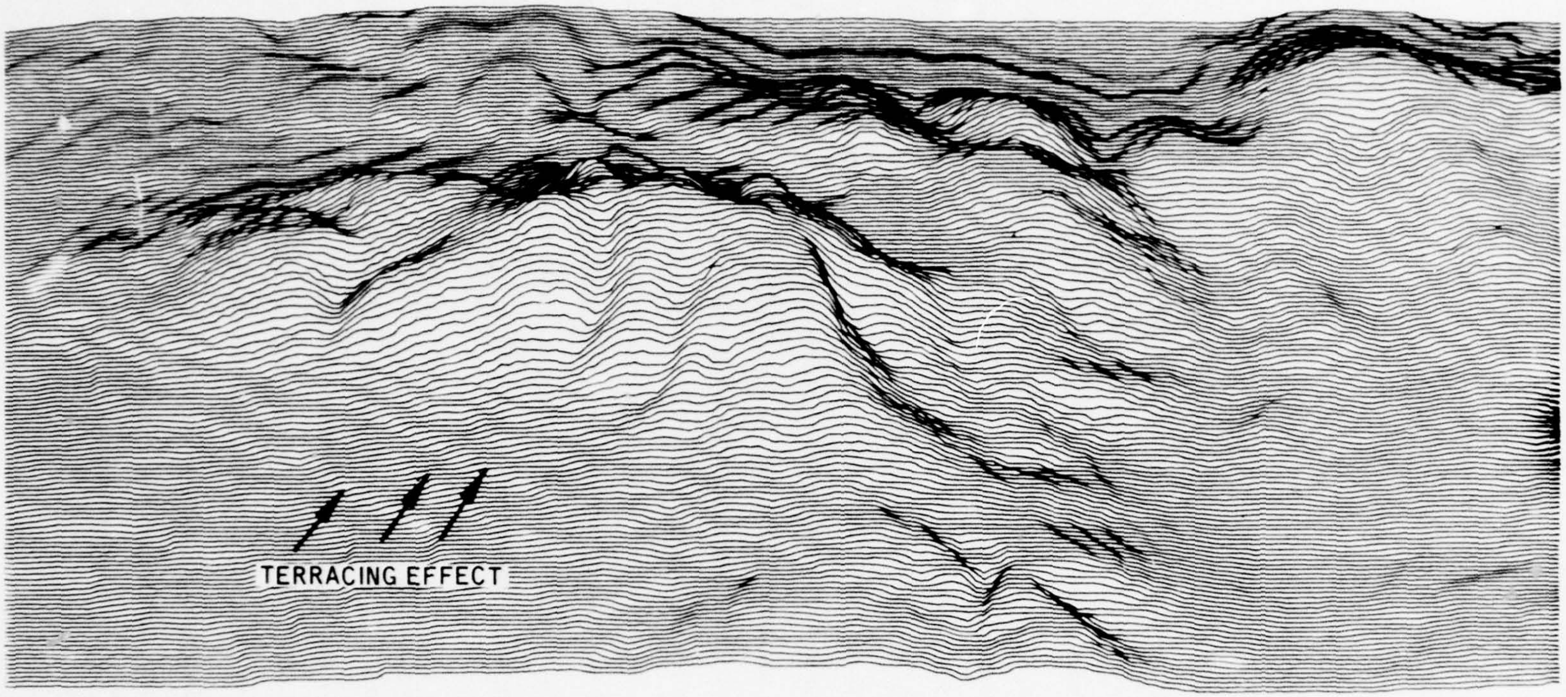
Figure 18. Topographic map of the Middle East site (map scale 1:50,000)

between grid points was set at a constant 50 m. The size of the subsequent grid array was 201 by 141 (NXRE by NYRE). The elevation values themselves were stored as integer multiples (metres).

73. Once the grid elevation array was constructed, it was edited and examined for errors. A method frequently used at the WES to quickly detect gross misrepresentations of the terrain surface is to portray the data by three-dimensional perspective plots. These plots allow rapid visual examination of large elevation data arrays. The computer generated perspective plots of the Middle East elevation grid array are shown in Figure 19. One of the prominent features in these plots is the terracing effect in the terrain surface along and parallel to contour lines. These terraces are not actual terrain conditions but are produced artificially by the elevation interpolation algorithm used in the computer program that generates the grid data from the contour data. This effect is a function of the grid spacing constant and diminishes as the grid spacing constant decreases.[9] With a grid spacing of 50 m, however, the perspective plots do show that the Middle East elevation grid array does approximate the terrain surface and, for purposes of providing input topographic data to SLOPEMAP, is adequate. If the terracing effect had been found to invalidate the data, the grid spacing constant could have been decreased and the grid elevation array regenerated. A better solution to the terracing artifacts would have been to eliminate the effect altogether by modifying the original interpolation algorithm. The latter solution would have required an extensive programming and testing effort and thus was considered out of the scope of work reported herein.

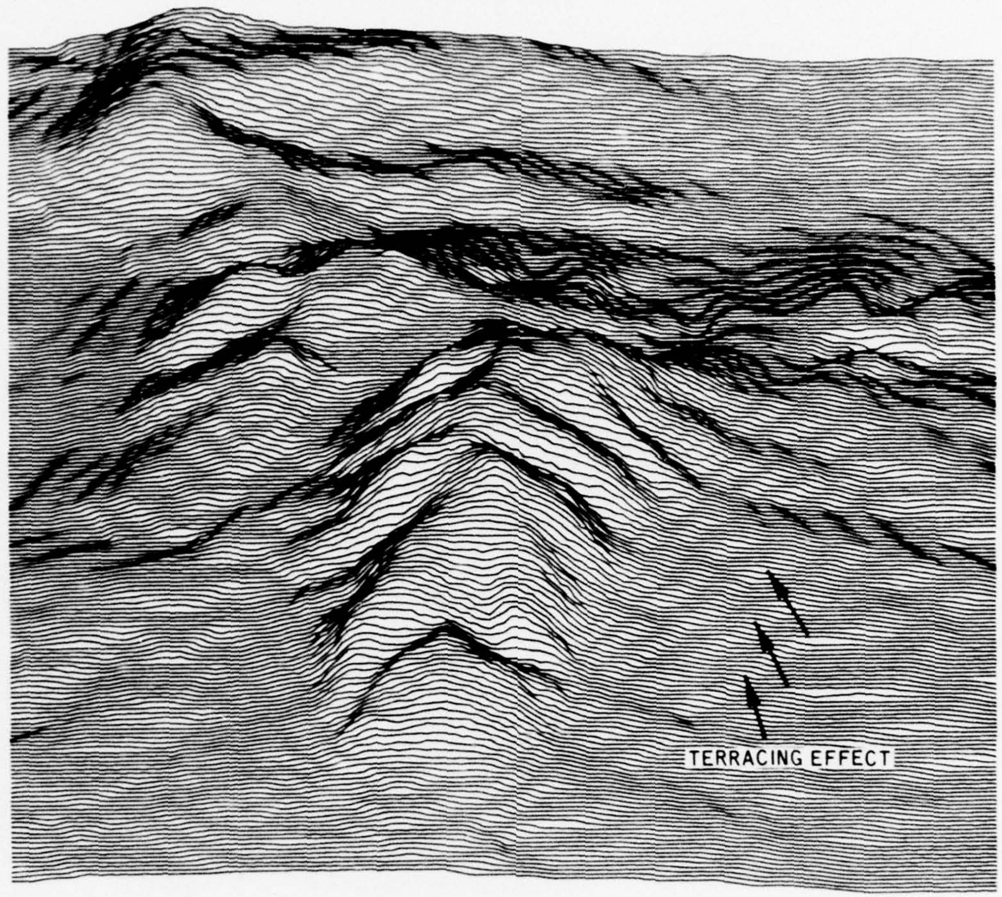
Selection of output forms

74. In general, the slope classes selected by the user will, of course, be problem dependent. However, in lieu of a priori knowledge of any class ranges, the user could apply the same technique to establish a tentative set of slope class ranges as was used in this study to establish a demonstration set of slope class ranges. The technique was to run SLOPEMAP with the slope class ranges set at 1-deg increments ranging from 0 through 90 deg. A graph was then produced for both the Middle



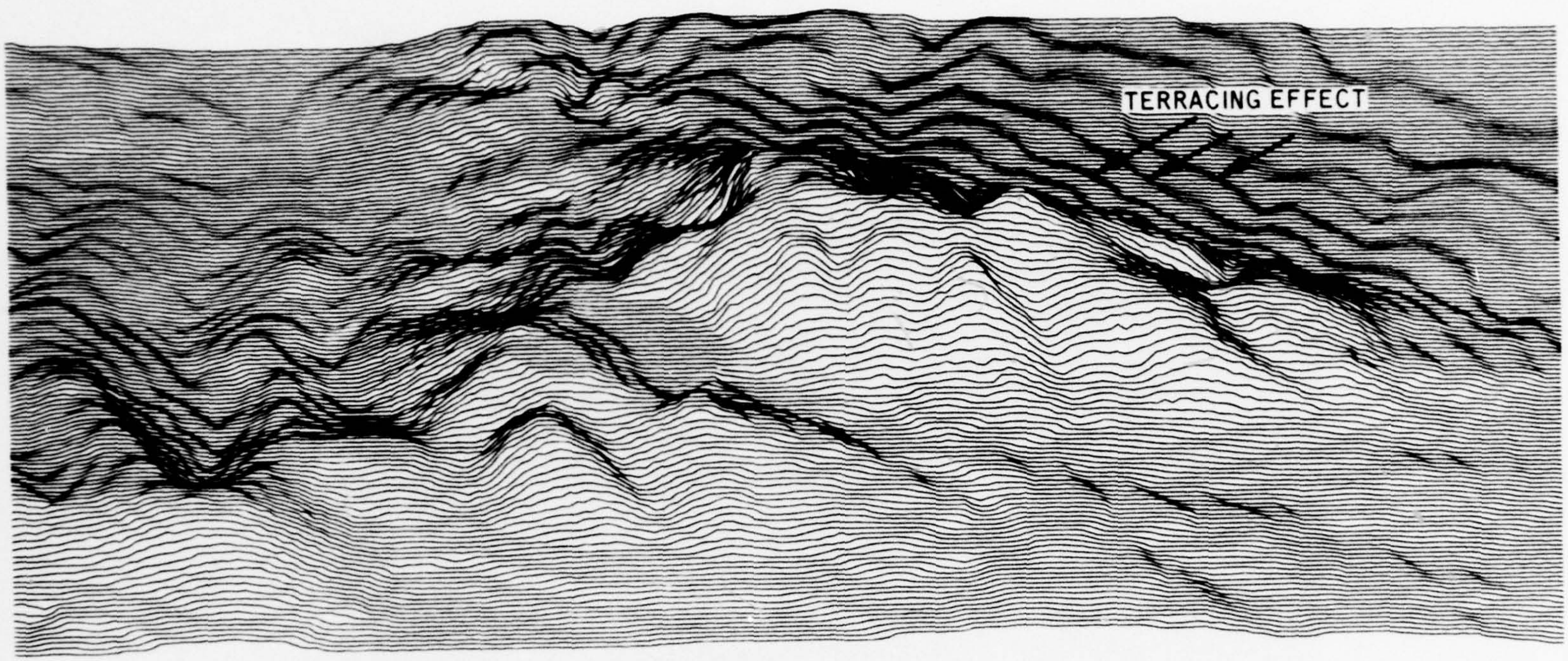
a. View looking north

Figure 19. Perspective plot of the Middle East terrain surface. The plot was drawn from the elevation grid array generated from the Middle East topographic map in Figure 18 (sheet 1 of 4)



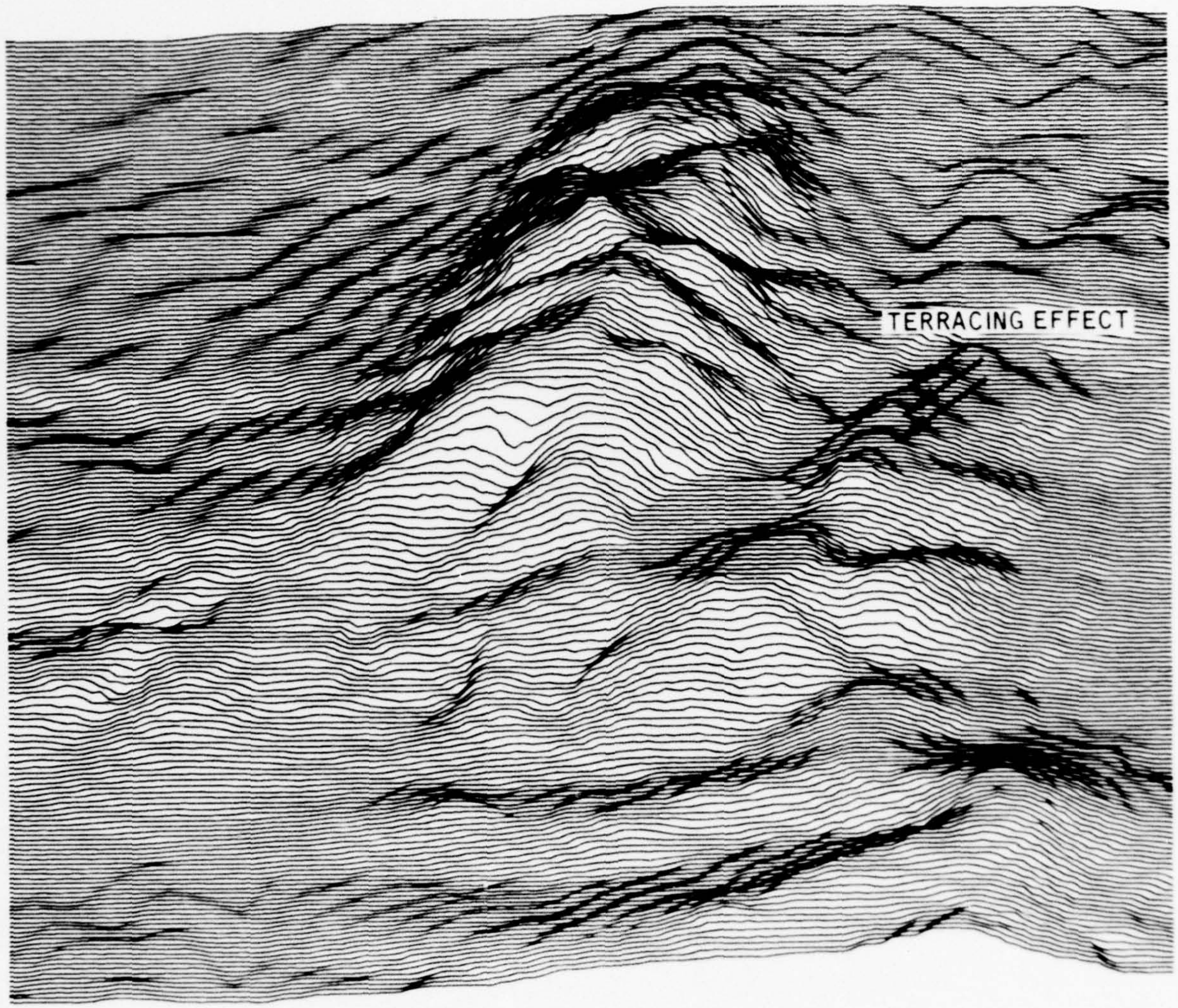
b. View looking east

Figure 19 (sheet 2 of 4)



c. View looking south

Figure 19 (sheet 3 of 4)



d. View looking west

Figure 19 (sheet 4 of 4)

East site and the Hunter-Liggett site (see paragraph 83) showing the accumulative percentage of the areas of the sites as a function of increasing slope values (Figure 20). Inspection of these graphs revealed that the distribution of slopes were very similar. Therefore, only one set of slope class ranges was selected for the two sites to demonstrate the slope classification option of SLOPEMAP. The class ranges selected were as follows:

Class	Range, deg
A	0 to <5
B	5 to <10
C	10 to <30
D	30 to <45
E	45 to 90

75. The following forms of output were then chosen to display the slope information for this example:

a. Swath dumps of calculated and classed slope values.

b. Magnetic tape of classed values only.

c. Punched cards with calculated values only.

d. CRT plot.

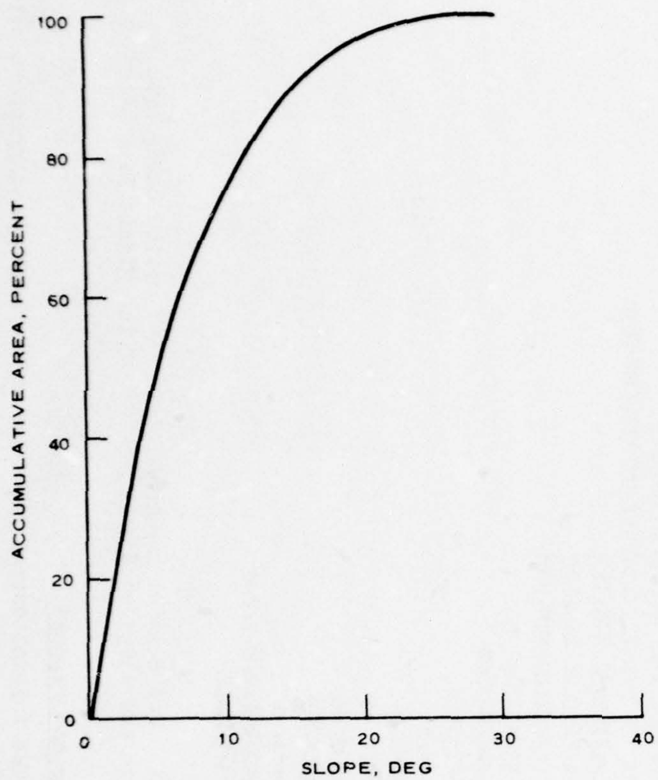
e. No smoothing options.

f. Slope vector components on magnetic tape.

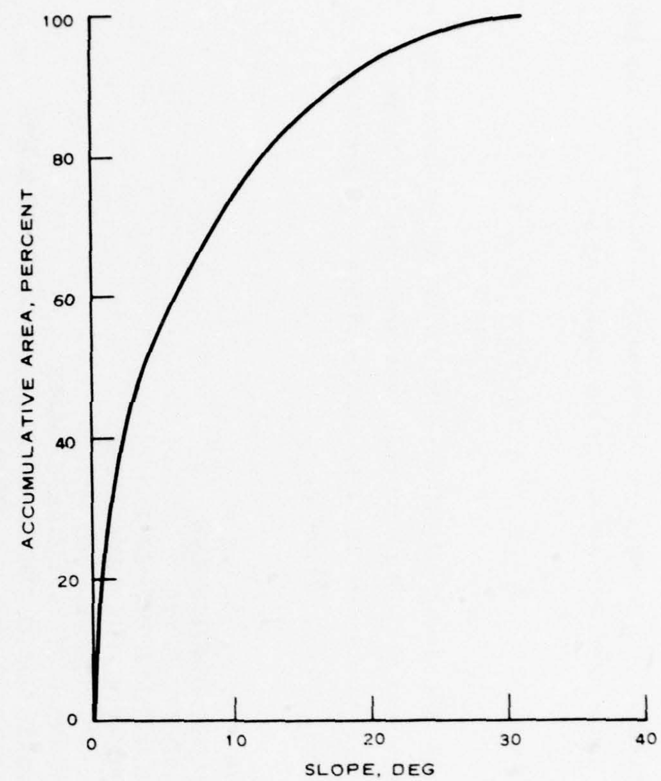
The control values necessary for execution of each of these selected forms of output are obtained from Table 4. For this example, the control values and their proper order of placement on the output option card (Figure 14d) are:

3 , 2 , 1 , 2 , 0 , 1 , 0.0

The drum plot scale value of 0.0 is used only as a dummy value, since the program does not use this value when called to output a CRT plot. It would have been sufficient to end the string of numbers with a comma, in which case the program would have substituted a value of zero. The minimum requirement, however, is at least a comma to define the necessary card fields. This is also true if one wishes to null (i.e. zero) any of



a. Middle East site



b. Hunter-Liggett site

Figure 20. Accumulative percentages of the areas of the demonstration sites as a function of slope

the option fields. For example, in the present illustration, the output option card could have been set up in the following way:

3 , 2 , 1 , 2 , , 1 ,

76. The JCL, data, and option cards necessary to execute the ex-example with a system loadable product tape are shown in Figure 21. The user should refer to Figure 16 if he wishes to use the $:SELECT: or source deck form of program input.

```
10##N
20$:IDENT:USERID,STRUVE
30$:PRODUCT:SLOPEC
40$:LIMITS:10,35K,,10000
50$:TAPE9:H*,T1D,,(TAPE NUMBER)
60$:TAPE7:10,X1D,,(TAPE NUMBER)
70$:TAPE7:21,X3DR,,,,CLASSED-VALUES
80$:MSG2:SAVE 21,STRUVE,USERID,CLASSED-VALUES OF SLOPES
90$:TAPE7:22,X4DR,,,,SLOPE-VECTOR
100$:MSG2:SAVE 22,STRUVE,USERID,SLOPE-VECTOR COMPONENTS
110$:TAPE7:24,X6DR,,,,CRT-PLOT
120$:MSG2:SAVE 24,STRUVE,USERID,CRT-PLOT
130$:FILE:30,X7R,10R
140$:FILE:31,X8R,10R
150$:FILE:32,X9R,20R
160$:DATA:I*
170#ELEVATION
180#DEGREES
190#0,5
200#5,10
210#10,30
220#30,45
230#45,90
240#-1,-1
250#3,2,1,2,0,1,0.0
260$:ENDJOB
```

Figure 21. Job control language, data, and option cards used to produce the slope map in Figure 24 of the Middle East site

Output forms and reports

77. The initial output reported on the high-speed printer, after

job execution, gives a listing of the input instructions, selected calculation units, slope class ranges, output options, and descriptive information contained on the input topographic data tape. The output report for the Middle East example is presented in Figure 22. If there had been an error detected in the input instructions, one of the error messages listed in paragraph 64 would have been printed in the initial output report, and the program would have then been terminated.

78. Following the initial output report of input instructions are the swath dump reports and values. Both the calculated and classed slope value reports contain the descriptive information stored on the input topographic data tape. However, in the classed slope value report (Figure 23), an additional listing containing a legend of the symbols used for the various class ranges is output. Also printed are the number of grid locations classed in each class range under the heading COUNT (e.g., class range 0 to <5 deg classed 14,490 grid locations as A). Immediately following the descriptive reports are the swath dumps themselves. To produce the swath dump slope maps, it is necessary to assemble the Middle East swath dumps of calculated and classed slope values (see paragraph 53). Once these report and swath dump options have been satisfied, no further use is made of the high-speed printer. The remaining output options (i.e. magnetic tapes, punch cards, CRT plots, and vector components) are output according to their respective formats and output devices (see paragraphs 54-57 and 62).

79. Other forms of analysis and display, which require SLOPEMAP products as input data, can be developed. An example of a postprocessing procedure used extensively in this study was the use of the classed value tape to produce slope map pictures. Through this method of producing slope maps, the best visual comparisons between manual and computer procedures can be made. This picture process is discussed in greater detail in paragraphs 80-82.

Slope map pictures

80. The contents of the magnetic tape output of classed slope values (see paragraph 54) consist of binary integers that represent the class ranges specified by the input instructions. For example, integers

```
------------------------------------------------------------
------------------------------------------------------------
 THE FOLLOWING IS A LIST OF YOUR INPUT INSTRUCTIONS.
------------------------------------------------------------
------------------------------------------------------------


THE SLOPE CALCULATION RESULTS ARE GIVEN IN DEGREES OF SLOPE (X100).

 THE SLOPE CLASS RANGES YOU INPUT FOR THE CALCULATION ARE AS FOLLOWS.
--------------------------------------------------------------------------------
                 0.            5.00
                 5.00         10.00
                10.00         30.00
                30.00         45.00
                45.00         90.00


THE FOLLOWING OUTPUT OPTIONS WERE SELECTED.
------------------------------------------------------------
PRINTER-CALCULATED VALUES
PRINTER-CLASSED VALUES
MAGNETIC TAPE-CLASSED VALUES
PUNCHED CARDS-CALCULATED VALUES
CALCOMP CRT MAP PLOT
MAGNETIC TAPE-SLOPE VECTORS

 THE FOLLOWING IS THE DESCRIPTIVE INFORMATION CONTAINED ON THE INPUT ELEVATION DATA MAG TAPE.
------------------------------------------------------------------------------------------------------------
         148
ERTS-1 MIDDLE EAST STUDY AREA, SAMPLE TOPOGRAPHIC DATA  SITE      SITE DIMENSIONS 10KM (EAST-WEST) BY 7KM (NORTH-SOUTH)
MAP SHEET NO. 3055 II, SCALE 1:50,000                              GRID SPACING 50 METERS
NORTHWEST CORNER OF SITE IS 6KM SOUTHEAST OF NAZARETH, ISRAEL     MARCH 26, 1975

 717.000 3615.000 0.     0.      727.000 3615.000 0.     0.      717.000 3608.000 0.     0.      727.000 3608.000 0.     0.
 1.00        201   141  50.0
------------------------------------------------------------------------------------------------------------
```

Figure 22. Initial computer output report giving input instructions and descriptive information on the input topographic data tape for the Middle East example

```
                                    DESCRIPTIVE INFORMATION
                       ------------------------------------------------------

       148
ERTS-1 MIDDLE EAST STUDY AREA. SAMPLE TOPOGRAPHIC DATA  SITE      'SITE DIMENSIONS 10KM (EAST-WEST) BY 7KM (NORTH-SOUTH)
MAP SHEET NO. 3055 II, SCALE 1:50,000                              GRID SPACING 50 METERS
NORTHWEST CORNER OF SITE IS 6KM SOUTHEAST OF NAZARETH, ISRAEL      MARCH 26, 1975

 717.000 3615.000 0.      0.      727.000 3615.000 0.      0.      717.000 3608.000 0.      0.      727.000 3608.000 0.      0.
 1.00          201    141   50.0
```

LEGEND FOR SLOPEMAP

SYMBOL	CLASS RANGE	COUNT	SYMBOL	CLASS RANGE	COUNT
A	0.00 - 5.00	14490	D	30.00 - 45.00	34
B	5.00 - 10.00	7082	E	45.00 - 90.00	5
C	10.00 - 30.00	6730			

NUMBER OF UNCLASSIFIED GRID LOCATIONS =   0

Figure 23. Classed slope value output report giving the descriptive information contained on the input topographic data tape and a legend for the classed slope map of the Middle East site

1-5 are stored on the tape generated in the Middle East example since five classes were defined on the data cards. Each integer corresponds to a legend symbol listed in the classed value swath dump report (e.g. 1≡A, 2≡B, ...5≡E).

81. After the classed slope value tape was generated by SLOPEMAP, it was used as an input tape for producing slope maps in a picture format on the WES film reader/writer.[10] Figure 24 is a slope map of the Middle East site generated on this device. Note that the terracing effects detected previously in the perspective plots of the elevation data (Figure 19) are discernible here in slope class range B . Also, since the options to smooth and remove isolated classed islands were not selected output options, numerous isolated blocks or squares are observed that tend to complicate portions of the slope map. This may or may not be of importance, depending on the type of problem for which data are required.

82. Figure 25 is the slope map produced when the smoothing option was selected and the islands were removed in a subsequent computer run.

Hunter-Liggett Site (1:25,000 Map Scale)

83. The steps followed to produce slope maps of the Hunter-Liggett site were the same as those previously used to produce slope maps of the Middle East site (see paragraph 71).

Site elevation data

84. The source of the elevation data was contour lines on 1:25,000-scale U. S. Army Topographic Command topographic maps identified as sheet 1755 IV NE, Series V895S, Edition 1-TPC, Stony Valley, California, and Sheet 1755 INW, Series V895S, Edition 1-TPC, Jolon. The contour interval used on these maps is 40 ft with supplementary contours at 20 ft. The portion of the maps designated in this study as the Hunter-Liggett site is shown in Figure 26. Each contour line within the 6.375- by 2.825-km site was digitized and processed by the same technique employed for the Middle East site to generate an elevation grid array. The spacing between grid points was set this time at a constant 25 m. The size of the subsequent array was 256 by 114 (NXRE

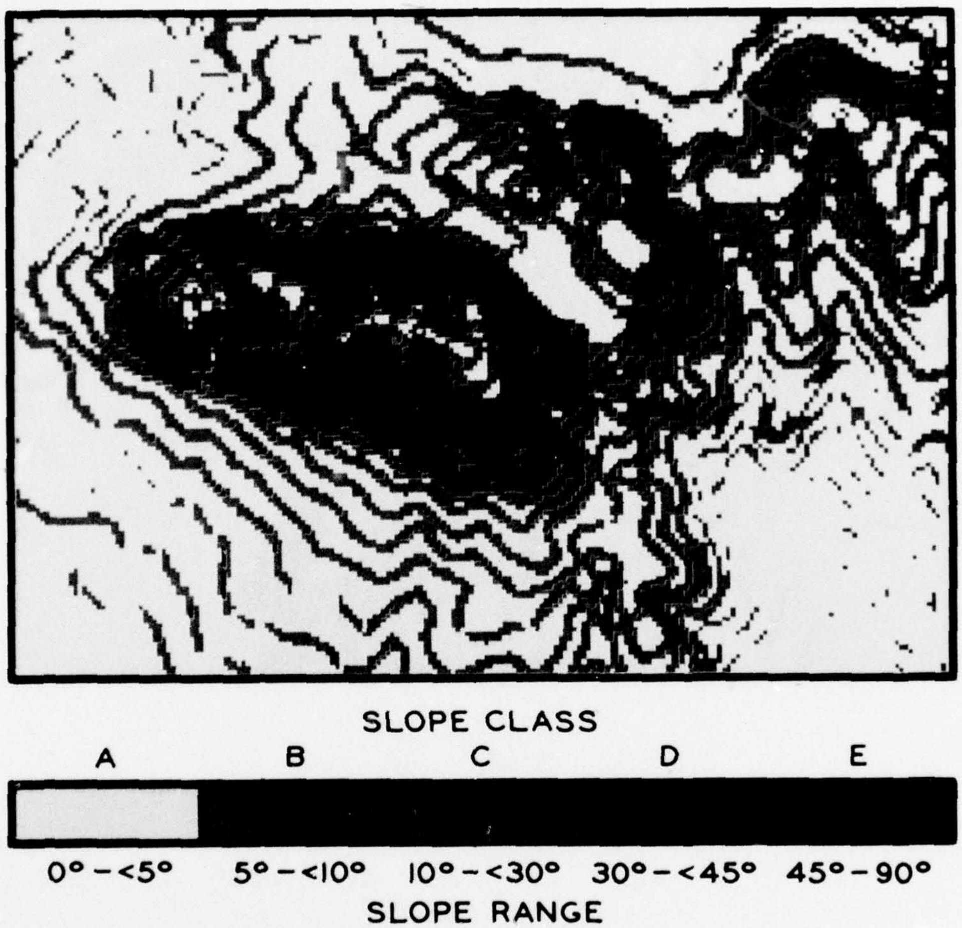


Figure 24. Slope map of Middle East site with smoothing and island removal options not requested (map produced with the WES film reader/writer

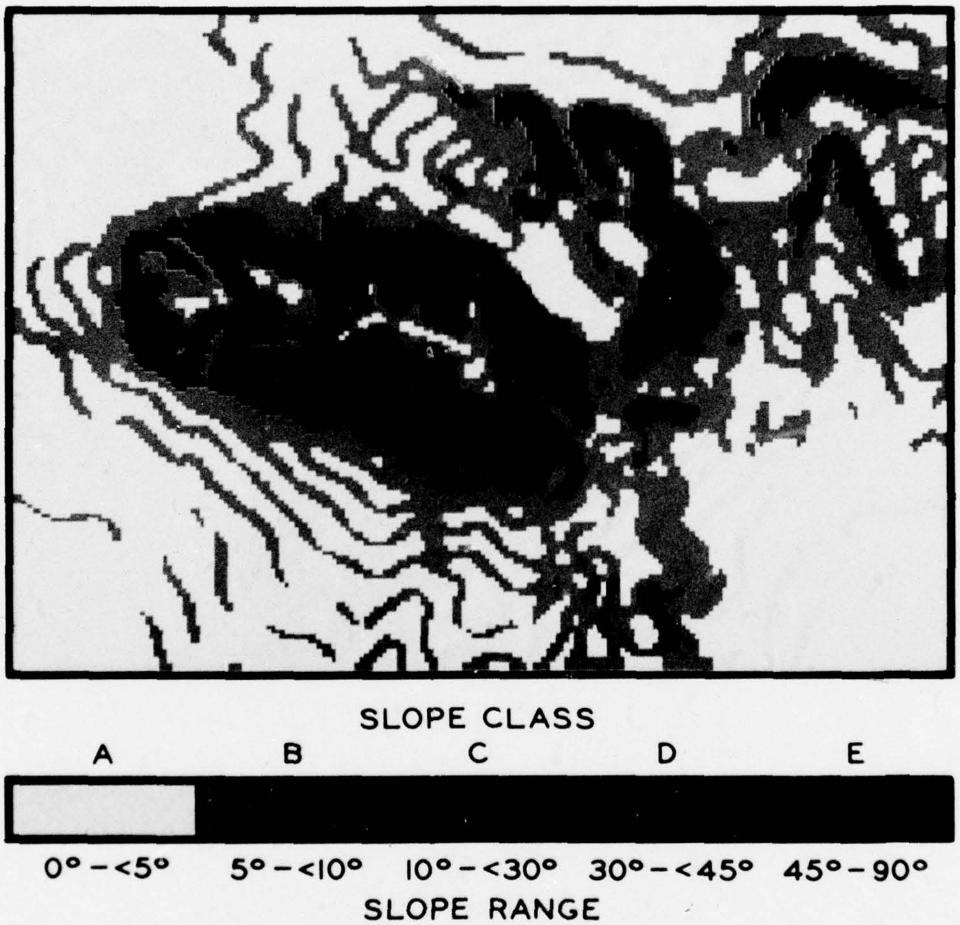


Figure 25. Slope map of Middle East site with smoothing and island removal options requested (map produced with the WES film reader/writer)

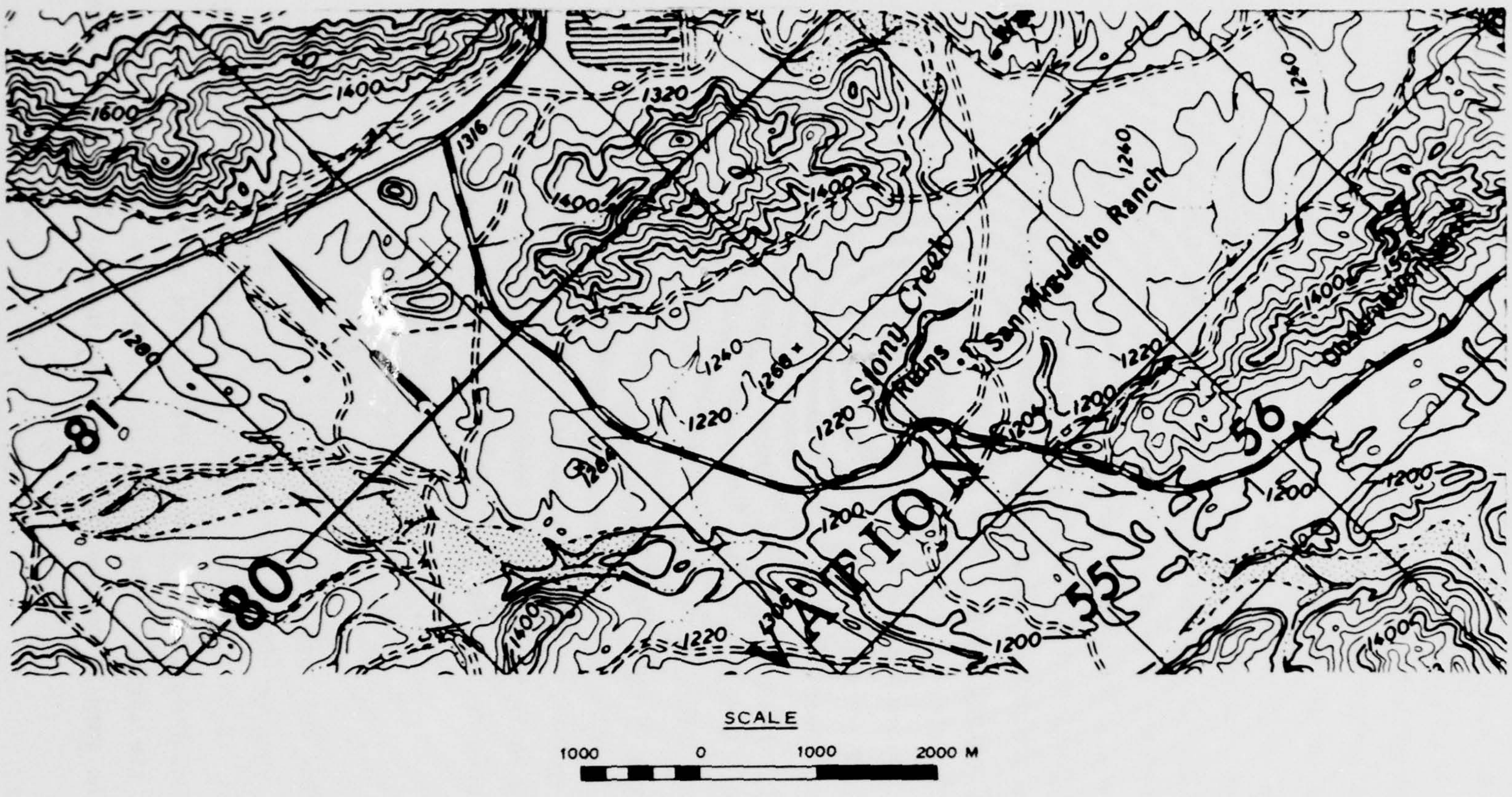


Figure 26. Topographic map of the Hunter-Liggett site (map scale is 1:25,000)

by NYRE). The elevation values were stored as integer multiples of decimetres, and the DATASC scale constant was set at 0.10.

85. Examination of the perspective plots (Figure 27) drawn from the Hunter-Liggett elevation grid array reveals the same terracing effect visible in the Middle East perspective plots (Figure 19) but on a much reduced scale. This is true because the Hunter-Liggett elevation grid array was constructed using a grid spacing constant of 25 m, which is smaller than that used to construct the Middle East elevation grid array. As before, however, the perspective plots show that the Hunter-Liggett elevation grid array does represent to a good approximation the three-dimensional terrain surface of the Hunter-Liggett site and is adequate for providing input topographic data to SLOPEMAP.

Selection of output forms

86. The class ranges listed in paragraph 74 were also used for this site. To demonstrate the flexibility of SLOPEMAP, the following forms of output were chosen:

a. Swath dump of classed slope values only.

b. Magnetic tape of classed values only.

c. No punched cards.

d. Drum plot.

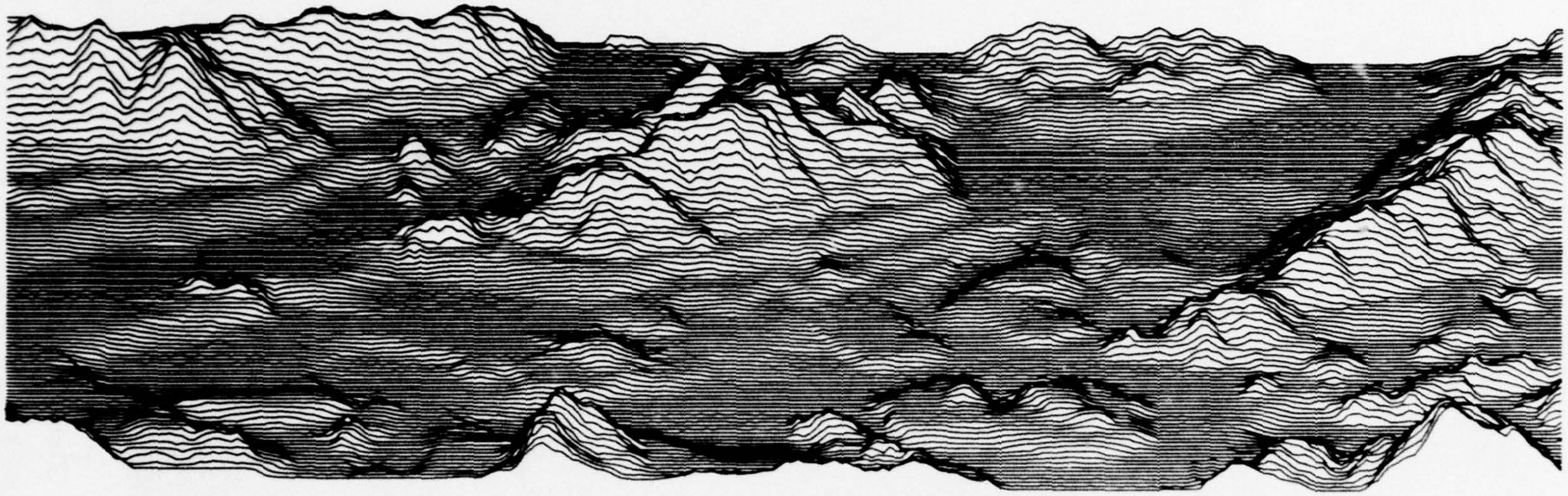
e. No smoothing options.

f. Slope vector components on magnetic tape.

The control values necessary to run each of these selected output options were again obtained from Table 4. For these selected forms, the output option card (Figure 14d) was set up as follows:

2 , 2 , 0 , 1 , 0 , 1 , 0.00004

87. The JCL, data, and option cards that were necessary to execute the example with a system loadable product tape are shown in Figure 28. Note that for illustrating the calculation units, the previously selected class ranges in degrees are now expressed as tangents of the angles. The slope class boundaries and areas would have been the same if degrees had been used instead of tangent values.

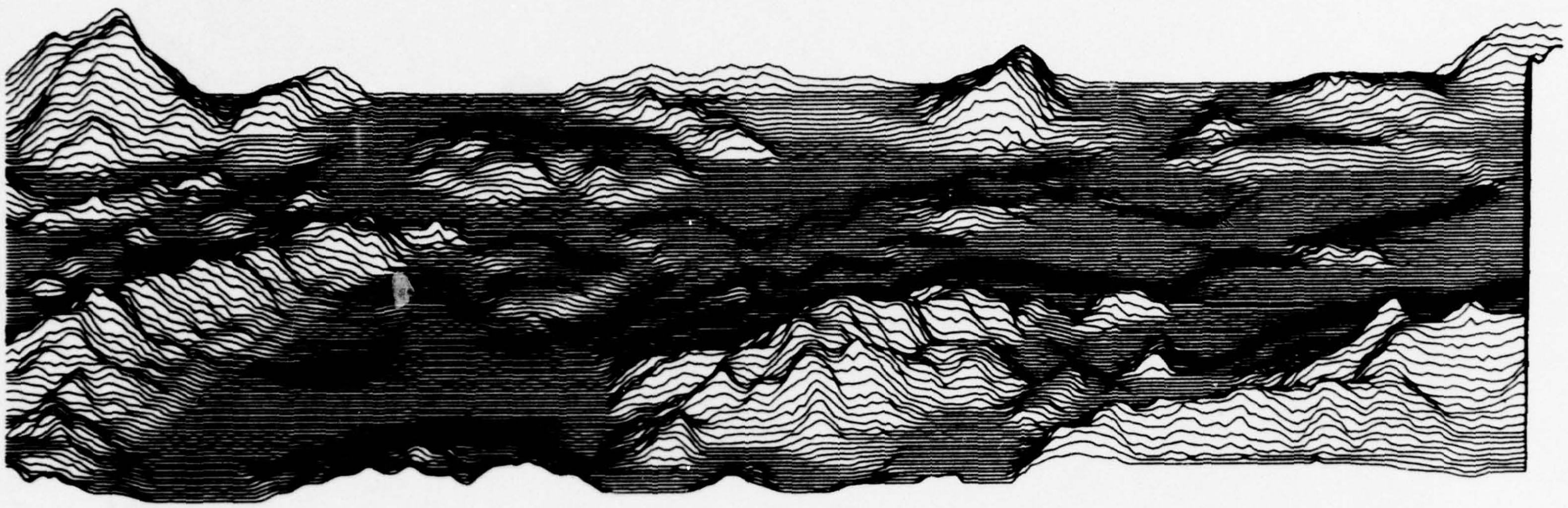


a. View looking northeast

Figure 27. Perspective plots of the Hunter-Liggett site. Plots were drawn from the elevation grid array generated from the Hunter-Liggett topographic map in Figure 26 (sheet 1 of 4)

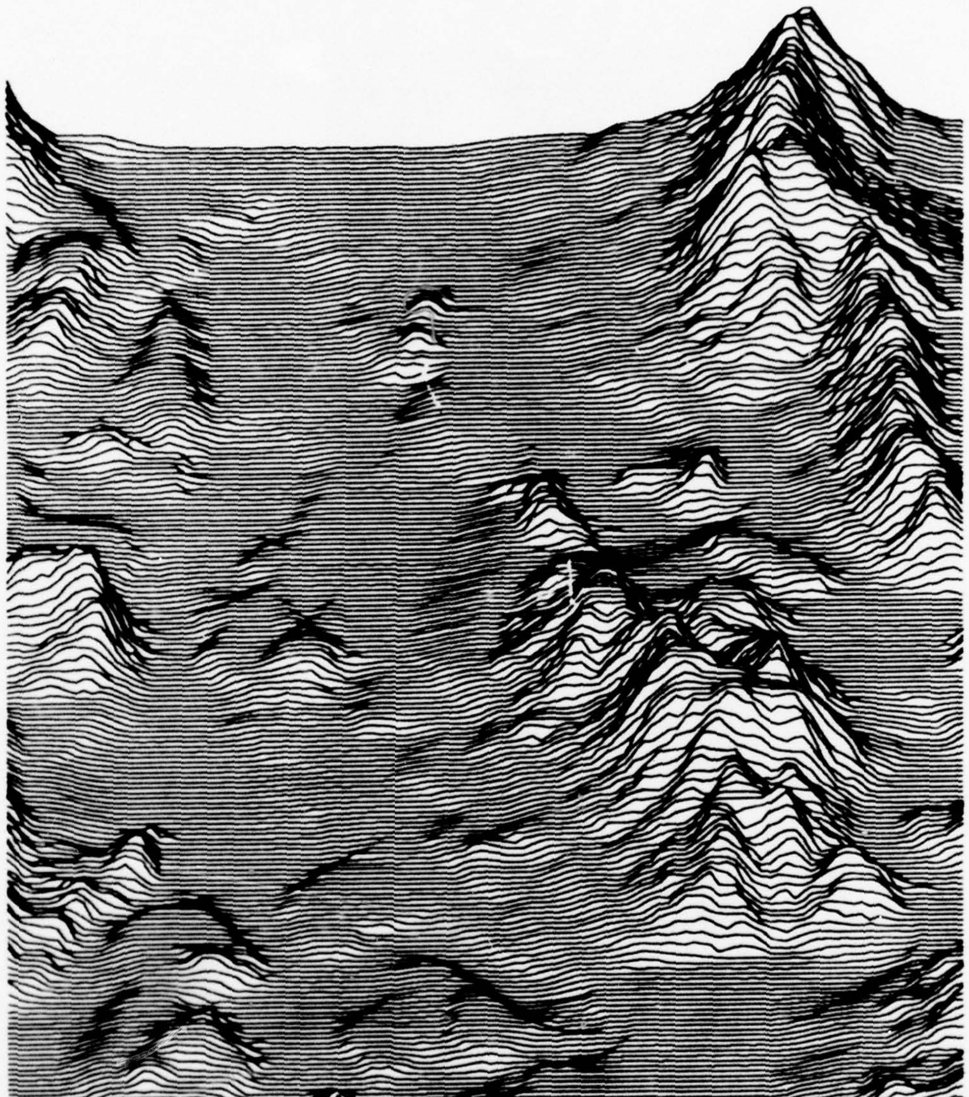
b. View looking southeast

Figure 27 (sheet 2 of 4)



c. View looking southwest

Figure 27 (sheet 3 of 4)



d. View looking northwest

Figure 27 (sheet 4 of 4)

```
10#N
20$:IDENT:USERID,STRUVE
30$:PRODUCT:SLOPED
40$:LIMITS:10,35K,,10000
50$:TAPE9:H*,T1D,,(TAPE NUMBER)
60$:TAPE7:10,X1D,,(TAPE NUMBER)
70$:TAPE7:21,X3DR,,,,CLASSED-VALUES
80$:MSG2:SAVE 21,STRUVE,USERID,CLASSED-VALUES OF SLOPES
90$:TAPE7:24,X6DR,,,,DRUM-PLOT
100$:MSG2:SAVE 24,STRUVE,USERID,DRUM-PLOT IN BALLPOINT
110$:FILE:30,X7R,10R
120$:FILE:31,X8R,10R
130$:FILE:32,X9R,20R
140$:DATA:I*
150#ELEVATION
160#TANGENT
170#0.0,0.08748866
180#0.08748866,0.17632698
190#0.17632698,0.57735027
200#0.57735027,1.0
210#1.0,99999999.0
220#-1,-1
230#2,2,0,1,0,1,0.00004
240$:ENDJOB
```

Figure 28. Job control language, data, and option cards used to produce the slope map shown in Figure 29 of the Hunter-Liggett site

Slope map pictures

88. The classed value tape was used again as an input tape to the WES film reader/writer to produce a slope map picture (see paragraph 81). The slope map produced from this process of the Hunter-Liggett site is shown in Figure 29. Isolated classed slope value islands and terracing effects that tend to complicate the appearance of the slope map are less evident than they were in the Middle East site (Figure 24). However, after SLOPEMAP was rerun with both smoothing options, the generated slope map (Figure 30) became less complicated.

Comparison of Slope Maps Constructed by Manual and Computer Methods

89. To compare slope maps constructed by a manual method with those constructed by the computer method developed in this study, both manually and computer-produced slope maps of the Middle East and Hunter-Liggett sites were constructed at the same map scale.

Manual procedures

90. Manually prepared slope maps of both the Middle East and Hunter-Liggett sites were constructed using the procedure discussed in Reference 11. Construction was begun by selecting the map scale and contour interval on templates (Figure 31) that coincided with that of the maps. The templates were transparent so that contour lines could be readily seen through them. This was necessary since the technique of ascertaining slope classes at every location required overlaying the template on the map and moving it freely over the contour lines. The slope classes were determined by finding the set of slope class circles or lines (sequence of vertical lines immediately to the left of the slope class circles) that bracketed the separation between two contour lines. For example, if at a given location on the topographic sheet the distance between a pair of contour lines was greater than the inner circle of a given slope class range but less than the outer circle for that range, the map location was classed as that slope class range and marked accordingly. This process was repeated many times over the

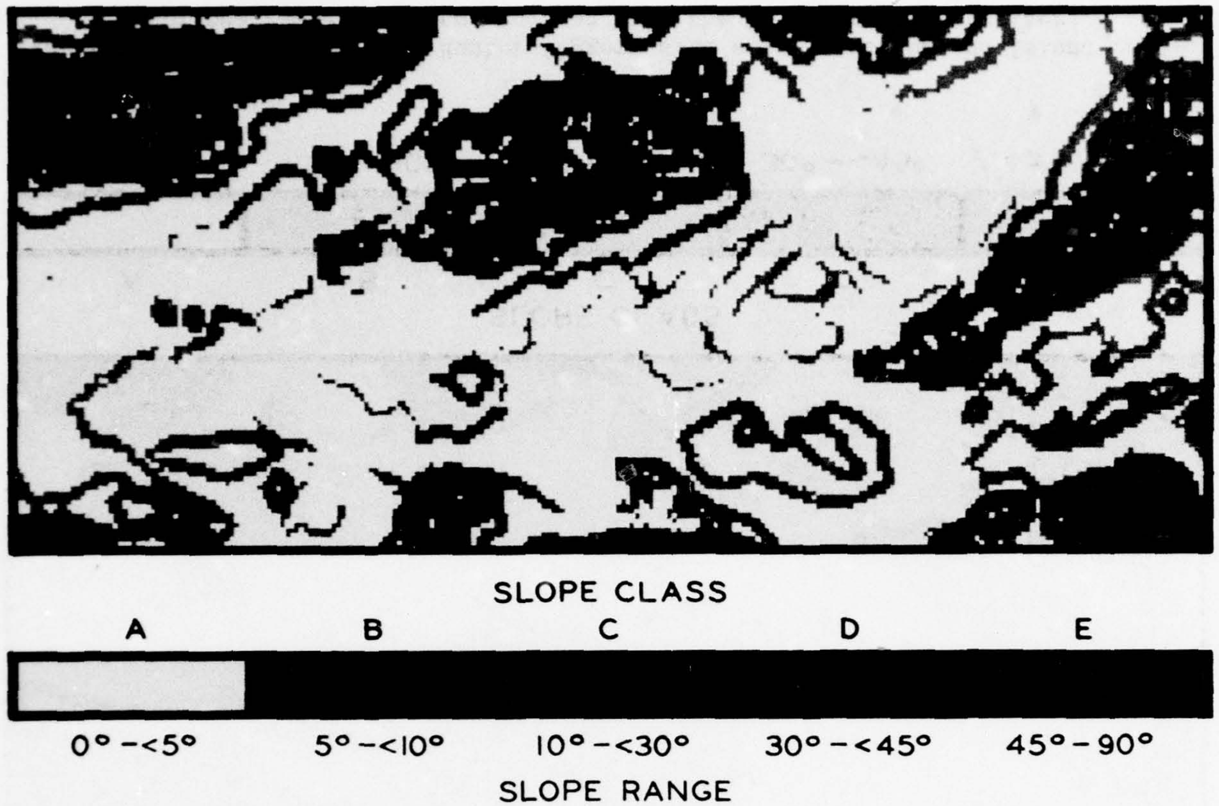


Figure 29. Slope map of the Hunter-Liggett site with smoothing and island removal options not requested (map produced with the WES film reader/writer)

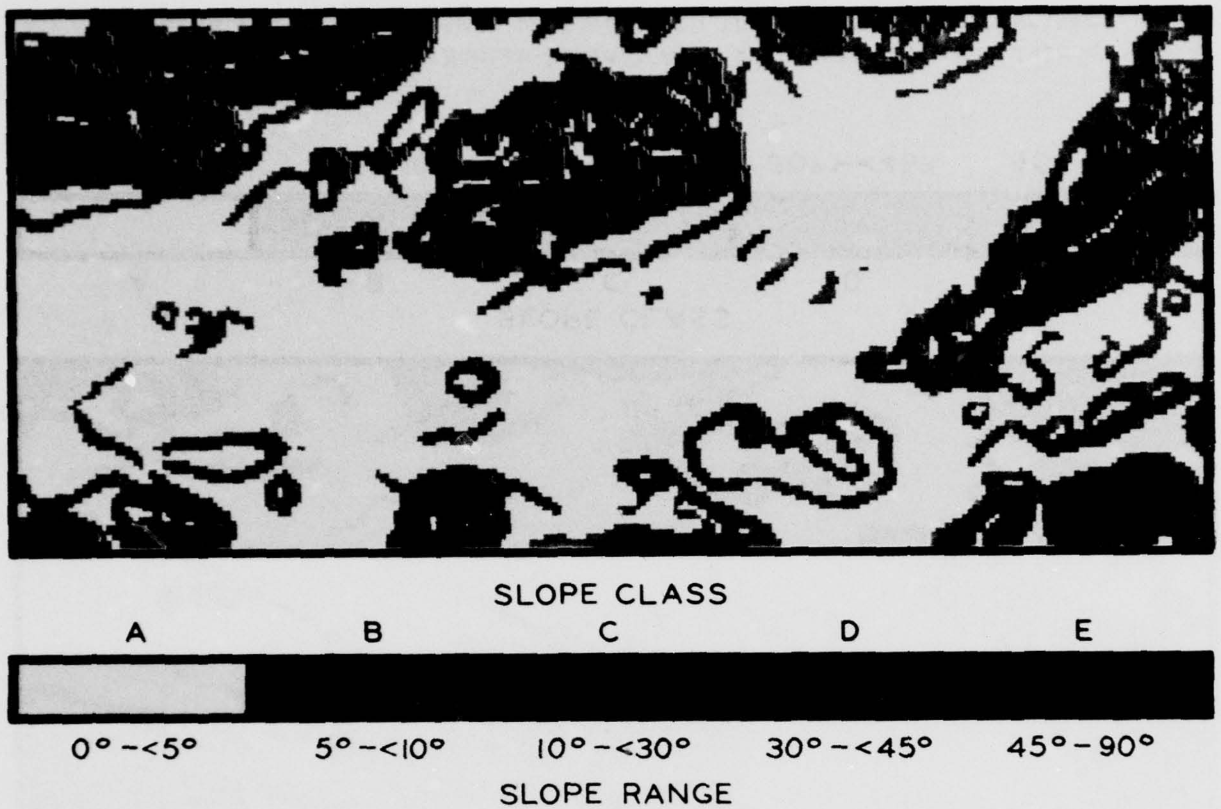


Figure 30. Slope map of the Hunter-Liggett site with smoothing and island removal options requested (map produced with the WES film reader/writer)

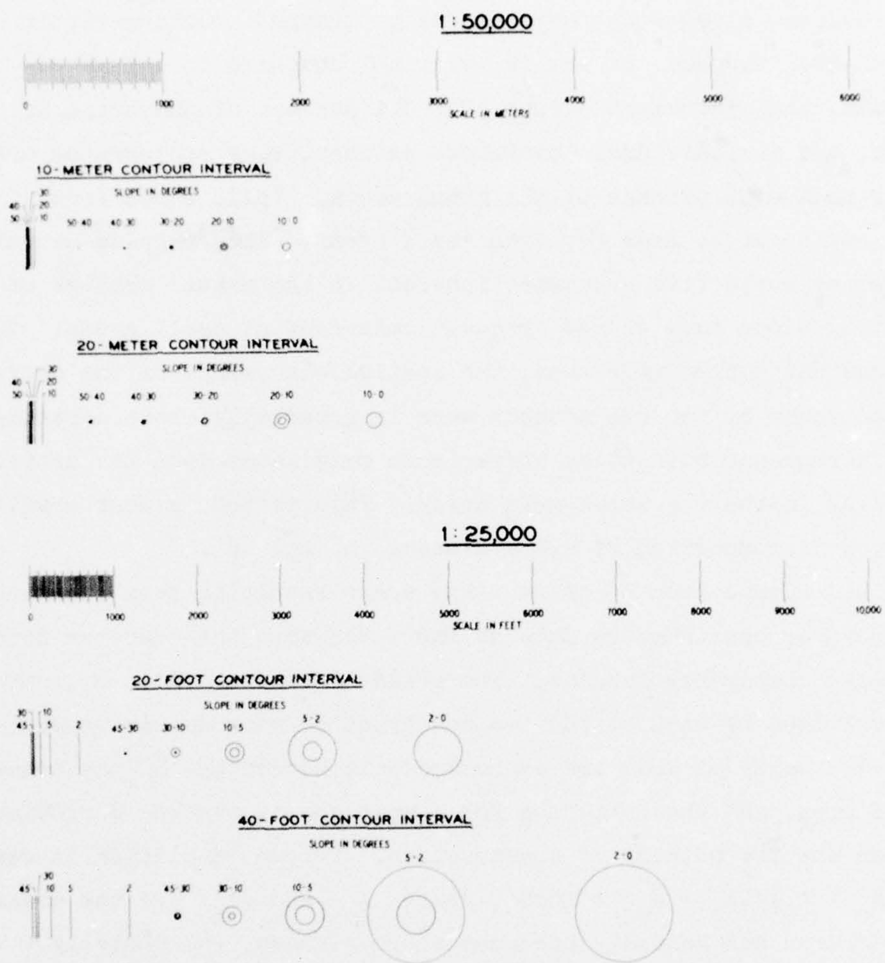


Figure 31. Template used to manually construct slope maps from the topographic data in Figures 18 and 26

entire topographic map until the slope conditions had all been determined. However, this process was very subjective at times, and some error in interpretation was expected. The procedure using vertical lines is, in principle, the same as for circles. Note that the reference line of each set is always the leftmost line of the set.

Comparison of manually and computer-produced slope maps

91. The computer-generated areas corresponding to slope classes A , B , and C for both the Middle East and Hunter-Liggett sites

are presented along with their manually produced counterparts in Figures 32-37. Classes D and E were not compared in this study since as a sum, they represented less than 0.1 percent of the total areas mapped, and as individual contiguous patches, they represented areas no larger than 0.01 percent of the total areas. Valid comparison, it was felt, could not be made for such small areas, since mapping oversights due to the subjective processes inherent in the manual methods of constructing slope maps caused frequent omissions of small areas. In view of these subjective processes, the spatial placements of the different classed areas by the two methods were in remarkably close agreement. The major disagreement in these comparisons originates from the artificial terracing in the elevation grid array. This effect is most readily observed in comparison of slope classes A and B .

92. Comparison of slope class areas resulting from the manual and computer construction methods indicates that the computer methods generated comparable results. The areas of classes A , B , and C as determined by each of the two construction methods are presented in Table 6. Units of area are expressed as a percentage of the total mapped area, and the criterion for comparison is percent deviation between the two methods of construction. Percent deviation is defined as $|A_c - A_m|/(A_c + A_m) \times 100\%$, where A_c and A_m are the areas of the computer and manually produced slope classes, respectively. Table 6 shows that the areal calculations agree very well except within class B. This is not surprising, however, since it was within this class that the terracing effect was most prevalent.

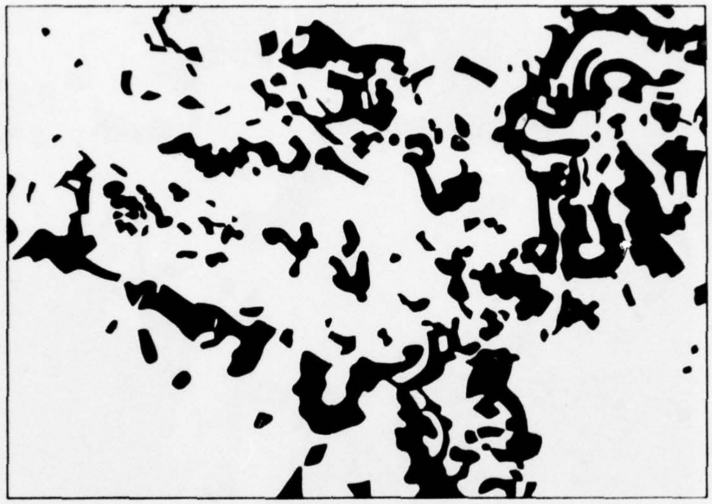
Computer Core Space, Time, and Cost Requirements for Executing SLOPEMAP

93. Estimates of computer core space, running times, and costs required for constructing slope maps using the automated procedure are presented below. The costs of constructing slope maps by manual and computer methods are also compared.

a. Manual

b. Computer

Figure 32. Comparison of slope class A (0-<5 deg, in black) in the Middle East site mapped by manual and computer methods



a. Manual

b. Computer

Figure 33. Comparison of slope class B (5-<10 deg, in black) in the Middle East site mapped by manual and computer methods

a. Manual

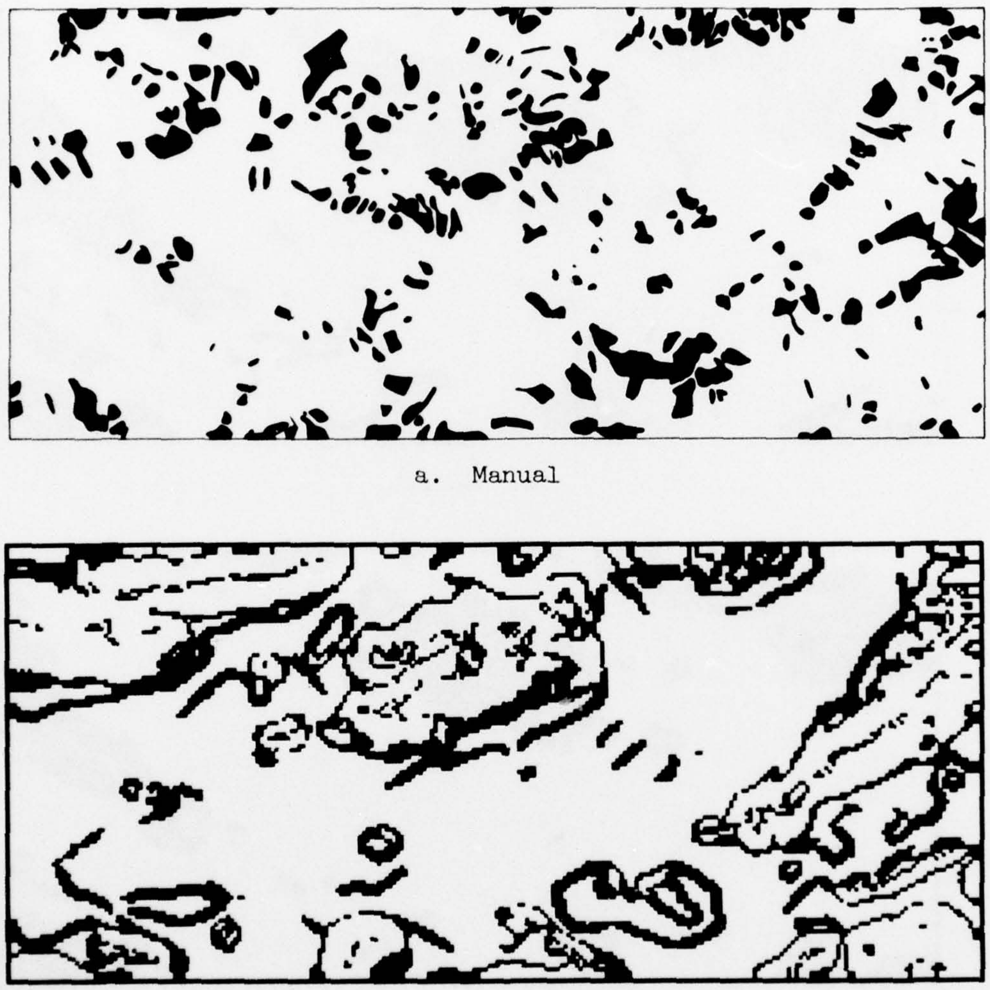
b. Computer

Figure 34. Comparison of slope class C (10-<30 deg, in black) in the Middle East site mapped by manual and computer methods

a. Manual

b. Computer

Figure 35. Comparison of slope class A (0-<5 deg, in black) in the Hunter-Liggett site mapped by manual and computer methods



a. Manual

b. Computer

Figure 36. Comparison of slope class B (5-<10 deg, in black) in the Hunter-Liggett site mapped by manual and computer methods

a. Manual

b. Computer

Figure 37. Comparison of slope class C (10-<30 deg, in black) in the Hunter-Liggett site mapped by manual and computer methods

Core space requirements

94. The necessary core space requirements should be known prior to running SLOPEMAP so that the correct specifications can be made on the \$:LIMITS: and \$:FILE: JCL cards (Figure 16). Compilation and load requirements are specified on the first and second \$:LIMITS: cards (lines 50 and 110, Figure 16), respectively. The requirements for the main program and each subroutine can be determined from Table 7 for the WES Honeywell G-635 computer. The necessary core space required to compile is determined by the largest of the routines of the program. Since the main program is always required and is the largest routine, the limits to compile should be set large enough to accommodate 37K words of space (a word on the Honeywell G-635 system consists of a bit string of 36 binary bits). Limits for program loading should be set to accommodate the accumulative load requirements of all the subroutines. For example, a limit equal to or greater than 34K words should be specified for loading all of program SLOPEMAP.

95. The random access file space requirements for file codes 30 and 31 (lines 250 and 260, Figure 16) can be determined from the total number of grid locations in the input elevation grid array. For an array with NXRE columns and NYRE rows, the total requirement is the product NXRE × NYRE expressed in terms of links (a link is 3840 words). For file 32 (line 270, Figure 16), the file space required is twice the product of NXRE and NYRE expressed in terms of links.

Processing times

96. The time required to compile SLOPEMAP is nominally 35 sec on the WES Honeywell G-635 computer. This time can double if reference maps and storage maps are requested as additional output forms to the compilation reports. This fact is of value only if the program is modified.

97. Processing times, once the program begins slope calculations, depend on the number and type of output options selected, as well as on the total number of grid locations in the input grid array. Runs were made with five grid arrays whose dimensions varied from 100 by 100 up to 500 by 500 to establish an approximate dependence of processing times

on size of the grid array. The runs were made with options to output a classed value swath dump and a magnetic tape of classed values. Two runs were made for each of the five grid arrays, one with both smoothing options requested and one without. The results of these runs are plotted in Figure 38 and should provide a basis for estimating processing times.

Processing costs

98. The cost estimates for running SLOPEMAP are, of course, computer and installation dependent. Since all of the development work was accomplished with the WES Honeywell computer system, only cost estimates based on the 1976 WES-system charges are presented. Compilation and loading charges for SLOPEMAP totaled approximately $4.60 without requesting reference and storage maps and $9.00 if maps were requested. These charges were not incurred if the program was executed each time from a system loadable product tape (see paragraph 68).

99. Processing costs as a function of input grid array size were derived from the same set of computer runs used to develop Figure 38; that is, the costs as a function of input grid size were determined for outputting a classed value swath dump and a magnetic tape of classed values for both smoothing and no smoothing requests. These costs are presented in Figure 39 as a function of the total number of elevation grid locations. Computer processing costs per unit area were also determined from these data and are presented in Figure 40 as a function of the grid spacing constants. Cost calculations using Figure 40 must include $2.00 for peripheral computer hardware (tapes and high-speed printer). No compilation charges are included in these curves since the runs were all made with a system loadable product tape.

100. The additional costs of running SLOPEMAP with other output options were determined from the example runs of the Middle East site that produced the slope map shown in Figure 24. The total cost of running SLOPEMAP for this job was about $26.00. The greater part of the increase in cost over an estimate obtained from Figure 39 was from the punching of cards that cost about $7.00. The remaining cost was $5.00 for the CRT plot, $4.00 for the slope vector tape, and $2.00 for the

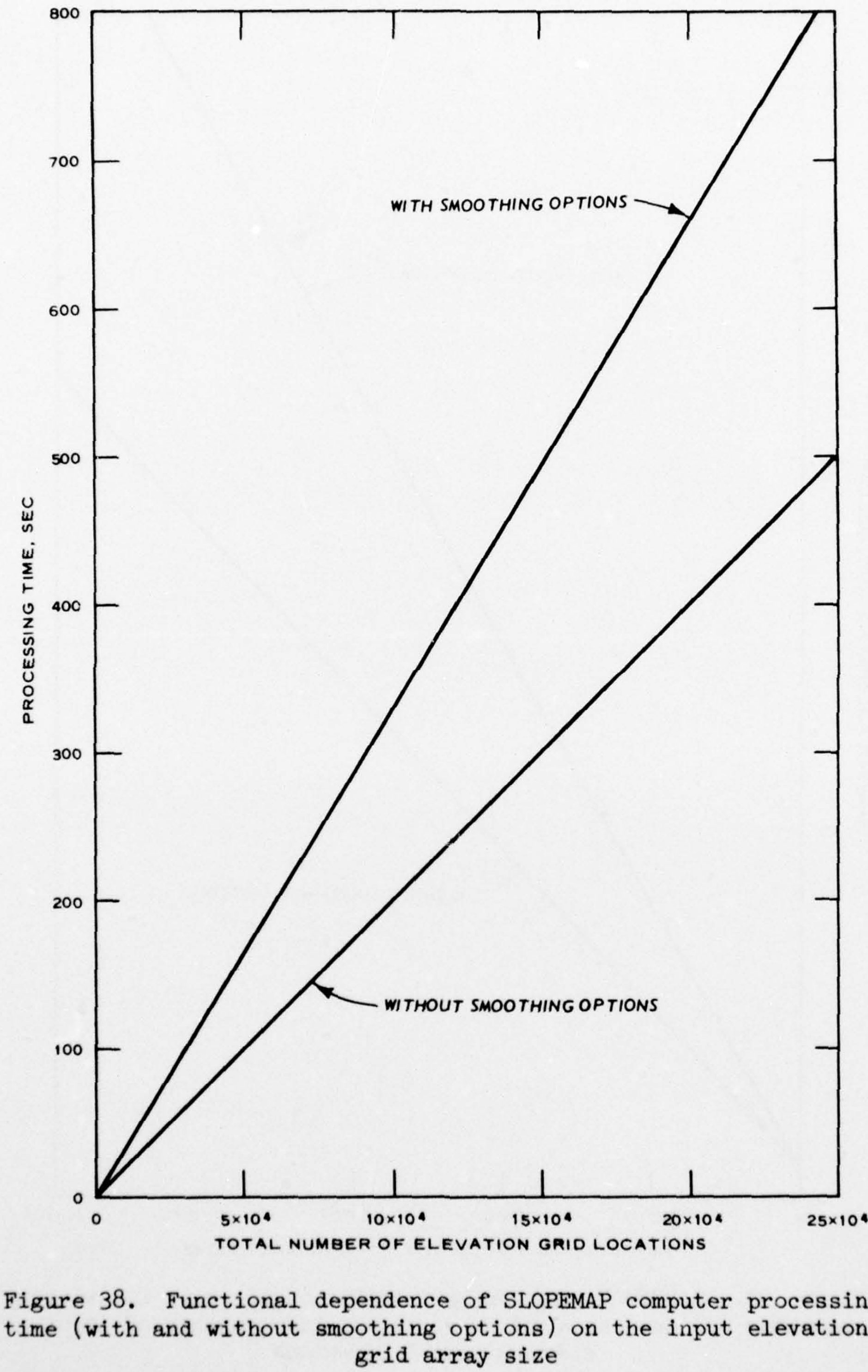


Figure 38. Functional dependence of SLOPEMAP computer processing time (with and without smoothing options) on the input elevation grid array size

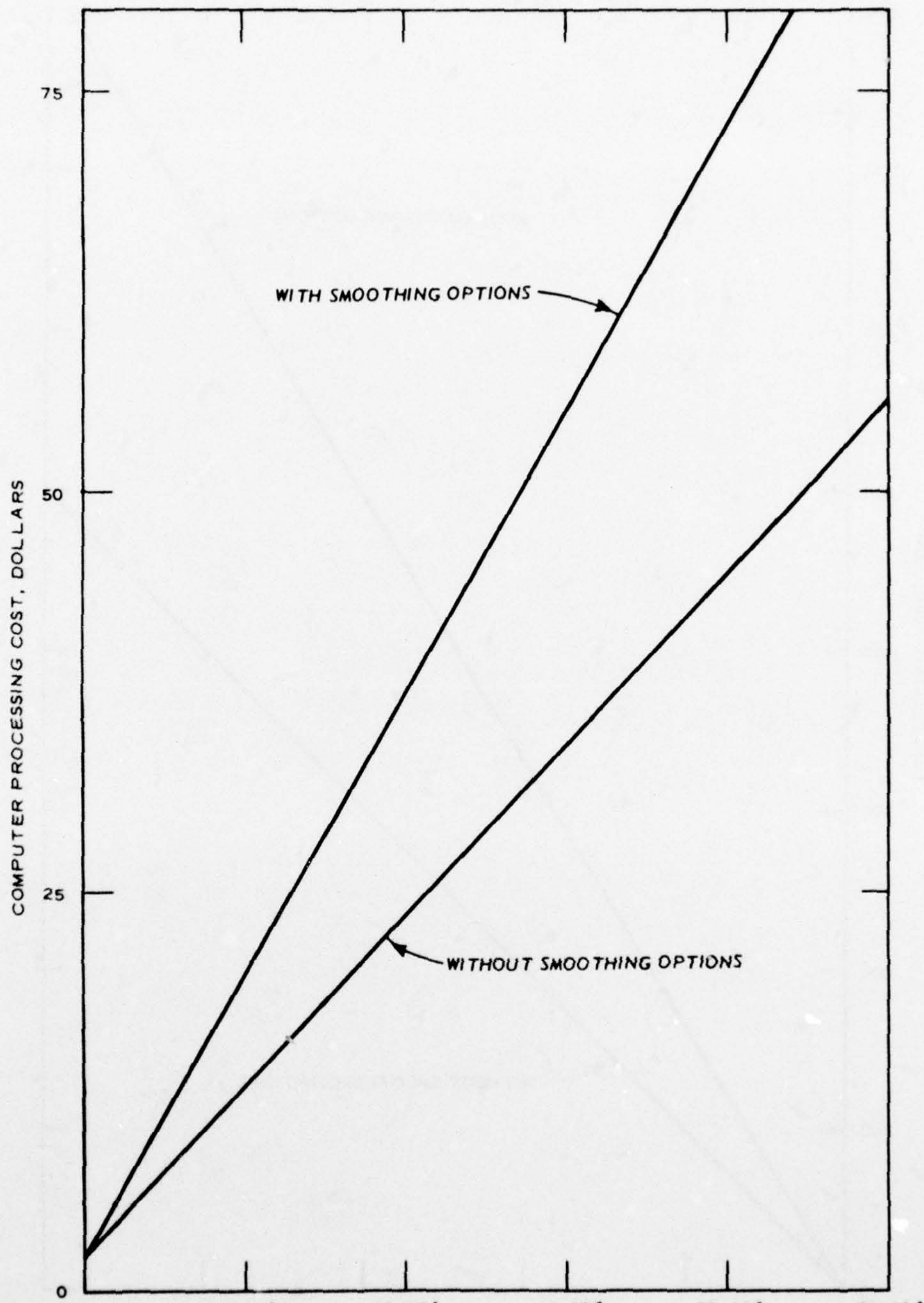


Figure 39. SLOPEMAP computer processing costs (with and without smoothing options) as a function of the total number of input elevation grid locations

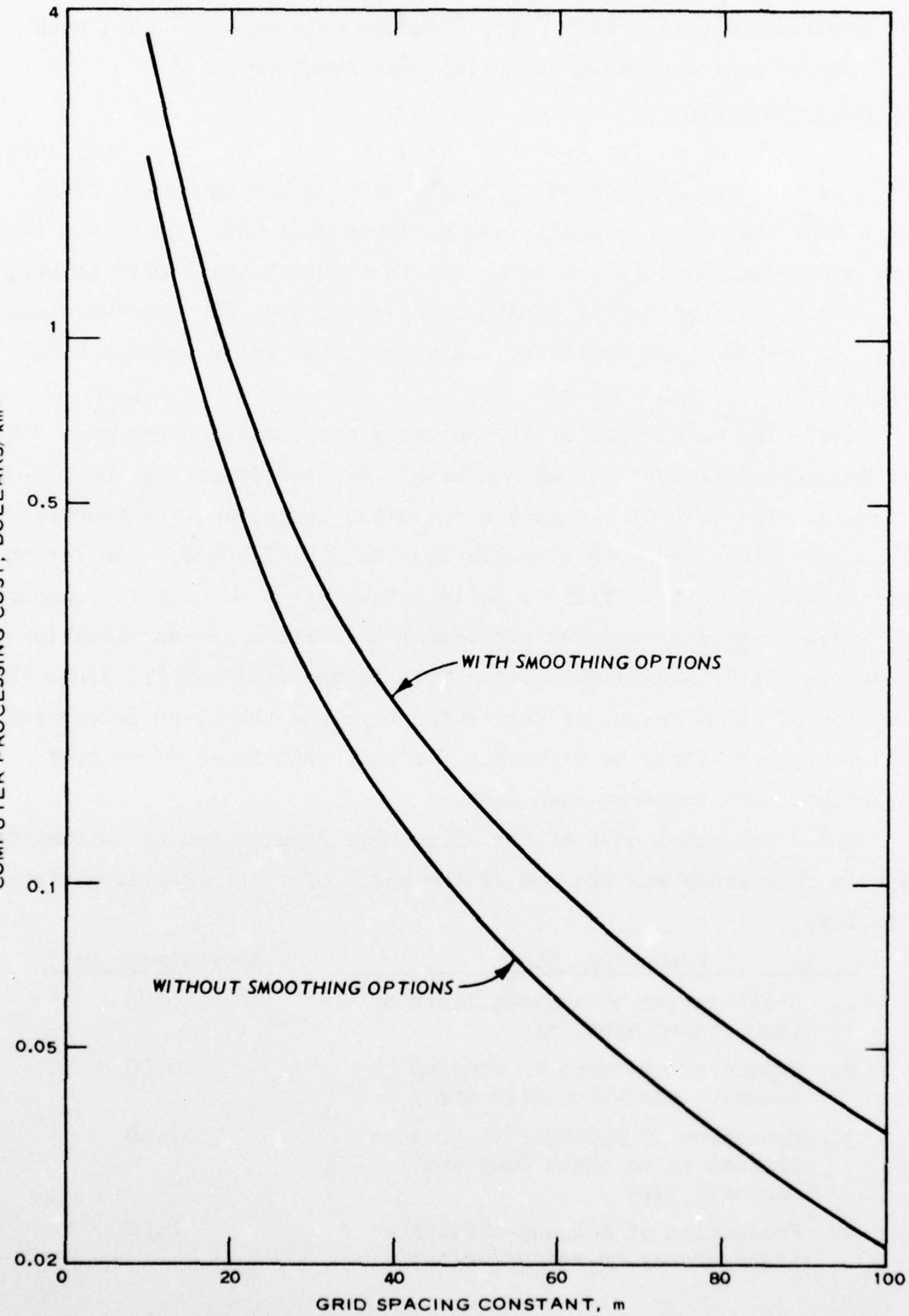


Figure 40. SLOPEMAP computer processing costs (with and without smoothing options) as a function of the grid spacing constant

calculated slope value swath dump. Running this same job with both smoothing options increased the total cost about $4.00.

Comparison of costs

101. The costs for constructing slope maps for this study automatically and manually can be compared by using the two study sites, Middle East and Hunter-Liggett (see paragraphs 71-88). Since the two sites were approximately the same size in terms of total grid points, the costs for automatically constructing slope maps for them were about equal. Therefore, the following costs presented are representative of both sites.

102. The total cost of the manually constructed slope maps with five delineated classes was approximately $150.00 (based on one man-day of labor). The cost of changing slope class ranges and constructing yet another slope map with five classes was also $150.00, even for the same topographic data. This is an important point to make for comparison, since repeating computer procedures to perform reclassification represents little additional cost. This is the real payoff, since the selection of class ranges is very subjective and the slope categories would more than likely be different for different types of project assignments that required such data.

103. The total cost of the slope maps constructed by automated means in this study was the sum of the costs of four production steps, as follows:

Production Step	Approximate Cost
1. Digitization of contour lines of input topographic map	$75.00
2. Execution of computer program to generate elevation grid array	25.00
3. Execution of SLOPEMAP to produce classed value swath dump and magnetic tape	12.00
4. Production of a black-and-white transparency on reader/writer	8.00

The sum of these production steps, which represent the cost of producing the first computer slope map, is $120.00. Note that succeeding slope

maps produced from the same input elevation grid array require only an additional $20.00 each. Hence, reclassification of given areas to obtain slope data for new baseline data requirements by computer methods becomes a very inexpensive process when compared with the costs of manually performing the same task. Further savings can be realized during subsequent reclassification runs, if the smoothing options are needed, by selecting as an output product a vector component tape during the initial run of SLOPEMAP and then using this tape as the input topographic data source during the subsequent runs. This avoids the necessity of having to rerun with the smoothing options during each reclassification and can represent a considerable savings (Figure 39) for large arrays.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

104. Conclusions drawn from this study are:

- a. The automated procedure (SLOPEMAP) developed in this study provides the Army and Research Community with a cost-effective way of generating reliable and accurate baseline data on slope. The scope of quantitative methods for assessing the environmental impact of military installation operations that require slope as a baseline data element have increased steadily. Digital data and maps of up to 36 user-selected class values of slope can be obtained with SLOPEMAP making it very flexible for satisfying specific data requirements.

- b. The initial cost of constructing slope maps using SLOPEMAP is comparable to manual methods; however, the cost of constructing reclassified slope maps to support new baseline data requirements using previously generated topographic input data can be from five to six times less using SLOPEMAP than the cost of manual methods (see paragraphs 102 and 103).

- c. A vector component tape should be output during the initial run of SLOPEMAP if smoothing options are selected and if subsequent reclassification runs are to be made. Reclassification runs should use this tape as the input topographic data source in order to reduce the time and cost of execution. This source of input prevents the computer from having to duplicate numerous calculations (see paragraph 38).

- d. CRT plots should be used during the early stages of slope map construction. After output needs have been established, the more accurate and more costly drum plot option can be used (see paragraph 57).

Recommendations

105. Recommendations that would increase the accuracy and utility of SLOPEMAP are:

- a. More accurate, reliable, and cost-effective techniques should be developed for producing elevation grid arrays from primary topographic data sources.

- b. SLOPEMAP should be made directly compatible with the DMATC topographic data tapes (see paragraph 42).

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AN AUTOMATED PROCEDURE FOR SLOPE MAP CONSTRUCTION. VOLUME I. DE--ETC(U)
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Table 1

Partial Derivatives of $f(x,y)$ Corresponding to the Algorithms for Calculating Slope

Vector	Plane	Surface	$\partial f/\partial x$	$\partial f/\partial y$
			Vector Algorithm*	
1	--	--	$(z_1 - z_0)/D$	0
2	--	--	$(z_2 - z_0)/2D$	$(z_2 - z_0)/2D$
3	--	--	0	$(z_3 - z_0)/D$
4	--	--	$(z_0 - z_4)/2D$	$(z_4 - z_0)/2D$
5	--	--	$(z_0 - z_5)/D$	0
6	--	--	$(z_0 - z_6)/2D$	$(z_0 - z_6)/2D$
7	--	--	0	$(z_0 - z_7)/D$
8	--	--	$(z_8 - z_0)/2D$	$(z_0 - z_8)/2D$
			Plane Algorithm	
--	1	--	$(z_1 - z_0)/D$	$(z_3 - z_0)/D$
--	2	--	$(z_0 - z_5)/D$	$(z_3 - z_0)/D$
--	3	--	$(z_0 - z_5)/D$	$(z_0 - z_7)/D$
--	4	--	$(z_1 - z_0)/D$	$(z_0 - z_7)/D$
			Surface Algorithm	
--	--	S	$(z_1 - z_5)/2D$	$(z_3 - z_7)/2D$
--	--	S'	$[(z_2 - z_6) - (z_4 - z_8)]/4D$	$[(z_2 - z_6) + (z_4 - z_8)]/4D$

* D is the grid spacing constant, and z represents elevation values at the different grid locations as designed for the vector, plane, and surface algorithms in Figures 3, 4, and 5, respectively.

Table 2

Comparisons* of the Vector, Plane, and Surface Algorithm

Slope Values with the Exact Values

Slope Difference Range, Deg	Percent Probability that the Difference Between the Algorithmic and Exact Slopes Fell Within a Specific Slope Difference Range		
	Vector Algorithm	Plane Algorithm	Surface Algorithm
0 to <1	25.3	21.9	93.8
1 to <2	43.2	40.4	6.2
2 to <4	19.1	25.3	0.0
4 to <6	10.9	10.9	0.0
6 to <11	1.5	1.5	0.0

* All comparisons were made with arrays containing 100 by 100 grid points.

Table 3

Index of DMATC Large-Scale Digital Terrain Elevation Data on Military Installations in the United States

Area	Scale	Coordinates
AZ, Fort Huachuca	1:25,000	Lat N 31°22'30" - 31°45'00" Long W 110°07'30" - 110°37'30"
CA, Camp Pendleton	1:24,000	Lat N 33°12'00" - 33°36'00" Long W 117°12'00" - 117°36'00"
CA, Fort Irwin	1:49,212	Lat N 35°07'30" - 35°37'30" Long W 116°17'30" - 116°57'30"
CA, Fullerton	1:49,212	Lat N 33°52'30" - 34°26'00" Long W 117°25'00" - 117°57'00"
CA, Fort Hunter-Liggett	1:50,000	Lat N 35°45'00" - 36°00'00" Long W 121°00'00" - 121°15'00"
CA, Fort Hunter-Liggett	1:25,000	Lat N 35°52'30" - 36°00'00" Long W 121°07'30" - 121°15'00"
KA, Fort Riley	1:50,000	Lat N 39°10'00" - 39°20'00" Long W 96°45'00" - 97°00'00"
NC, Camp Lejeune	1:24,000	Lat N 34°30'00" - 34°48'00" Long W 77°06'00" - 77°30'00"
NC, Camp Lejeune	1:50,000	Lat N 34°30'00" - 34°48'00" Long W 77°00'00" - 77°30'00"
OK, Fort Sill	1:50,000	Lat N 34°32'00" - 34°49'56" Long W 98°15'00" - 98°47'15"
TX, Fort Hood	1:50,000	Lat N 31°00'00" - 31°30'00" Long W 97°30'00" - 98°00'00"
VA, Quantico	1:24,000	Lat N 38"24'00" - 38°42'00" Long W 77°12'00" - 77°36'00"

Table 4

Control Values for Output Option Card

Output Option	Card Field*	Control Value	Output Description
Swath dump	1	0	No output
		1	Calculated values only
		2	Classed values only
		3	Calculated and classed values
Magnetic tape	2	0	No output
		1	Calculated values only
		2	Classed values only
		3	Calculated and classed values
Punched cards	3	0	No output
		1	Calculated values only
		2	Classed values only
		3	Calculated and classed values
Drum or CRT plot	4	0	No output
		1	Drum plot only
		2	CRT plot only
Smoothing options	5	0	No processing
		1	Smoothing only
		2	Island removal only
		3	Smoothing followed by island removal
Vector components	6	0	No output
		1	Output slope vector components onto magnetic tape
Drum plot scale	7		Drum plot scale value in decimal form (e.g. 1:25000 → 0.00004)

* Card fields are defined by the field delimiters (e.g. blanks and commas). The length of each field depends solely on the placement of the delimiter on the card.

Table 5

File Codes and Descriptions of the Input and Output Files Used in SLOPEMAP

Function	File Code	Type File*	Description of Contents
Input	10	Sequential	Elevation data
Input	11	Sequential	Slope vector data
Output	20	Sequential	Calculated slope values
Output	21	Sequential	Classed slope values
Output	22	Sequential	Slope vector components
Output	23	Sequential	Drum plot
Output	24	Sequential	CRT plot
Scratch	30	Random	Calculated slope values
Scratch	31	Random	Classed slope values
Scratch	32	Random	Slope vector components

* The sequential files most frequently used during SLOPEMAP development were magnetic tape and permanent disc files (PRMFL).

Table 6

Comparison of Computer and Manually Classed Slope Class Area

Class*	Area** of Computer Classed Slope Class	Area** of Manually Classed Slope Class	Percent Deviation
	Middle East Site		
A	51.0	55.1	3.9
B	29.1	23.2	11.3
C	19.8	21.4	3.9
	Hunter-Liggett Site		
A	57.1	65.4	6.8
B	20.9	14.8	17.1
C	22.0	19.8	5.3

* Classes D and E represented less than 0.1 percent of the total areas classed and thus were not compared.

** Areas are expressed in percentage of total area mapped.

Table 7

SLOPEMAP Computer Core Space Requirements

Subroutine Name	Subroutine Function	Compilation Requirements*	Load Requirements*
MAIN	Calculates slopes	37K	18K
SMOOTH	Averages slope vector components	28K	2K
ISLAND	Removes classed value islands	27K	1K
CALSWH	Prints calculated slope values	27K	2K
CLSSWH	Prints classed slope values	32K	2K
CRTPLT	Produces a CRT plot	29K	4K
DRMPLT	Produces a DRUM plot	28K	2K
CRDCAL	Punches a card deck of calculated slope values	26K	1/2K
CRDCLS	Punches a card deck of classed slope values	26K	1/2K
TAPCAL	Produces a magnetic tape of calculated values	25K	1/2K
TAPCLS	Produces a magnetic tape of classed values	25K	1/2K
TAPVEC	Produces a magnetic tape of slope vector components	25K	1K

* Units for compilation and load requirements are given in terms of Honeywell G-635 system words. Each word contains a string of 36 binary bits.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Struve, Horton

An automated procedure for slope map construction / by Horton Struve. Vicksburg, Miss. : U. S. Waterways Experiment Station. 1977.

2 v. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; M-77-3)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 4A152121A896, Task 01, Work Unit 006, Project 1E865803M730.

Includes bibliography.

Contents: v.1. Description and instructions for use of the automated procedure. (Distribution unlimited).--v.2. Listing and glossary for program SLOPEMAP. (Distribution limited to U. S. Government agencies only).

1. Computer programs. 2. Mapping. 3. SLOPEMAP (Computer program. 4. Slopes. 5. Topographic maps. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report; M-77-3.

TA7.W34 no.M-77-3